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OPERATION

GREENHOUSE

SCIENTIFIC DIRECTOR'S REPORT

ANNEX 6.3 COMBAT VEHICLE EXPOSURE

NUCLEAR EXPLOSIONS

1951

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COMBAT VEHICLE EXPOSURE

by

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Aberdeen Proving Ground
Maryland

August 1952

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Preface

Since the first operational use of the atomic bomb at Hiroshima and Nagasaki, much thought and study have been given to the strategic employment of atomic weapons in future warfare, but comparatively little study has been given to the possible tactical use of such weapons. However, new developments in weapons design have served to emphasize the tactical possibilities of nuclear weapons. This resulting change in the concept of the use of atomic weapons has developed to the point that it is even receiving attention in the public press (see V. Bush, The Weapons We Need for Freedom, Reader's Digest, January 1951).

With the recognition that there is reason to investigate the tactical use of atomic weapons, new possibilities and new problems arise. Project 6.3 was one result of the trend to tactical considerations.

Acknowledgments

The personnel directly connected with Project 6.3, Operation Greenhouse (i.e., those who participated in the work on the Atoll), appreciate the great amount of aid they have received in preparing for and conducting the test. Although space cannot permit enumeration of all the individuals or even all the organizations whose assistance was gratefully received, a few will be mentioned as representative.

In the preliminary work at Aberdeen Proving Ground, the wholehearted cooperation of several other organizations, whose members did not have full knowledge of the project or its objectives, enabled us to meet our deadlines. The assistance of the Electronic Measurements Branch of the Ballistic Measurements Laboratory in the preparation of electronic equipment, of the Automotive Division of Development and Proof Services in the preparation of the vehicles, and of the Explosion Kinetics Branch of the Ordnance Engineering Laboratory in the prediction of blast effects is gratefully acknowledged.

On the Atoll, the aid received from Project 3.4, the personnel of Sandia Corporation, in the preparation and calibration of our magnetic recorders cannot be overemphasized. Their assistance was an example of the spirit of cooperation and mutual interest which pervaded all technical levels of the Task Force. As another example, the personnel of Holmes and Narver, without exception, were ready and willing to assist in all matters in which they could possibly aid.

Numerous other organizations assisted in securing portions of the data of interest to us. Where these portions appear in the body of the report, we have attempted to make proper acknowledgment.

Finally, the competence and consideration of our Program Director, Comdr. Victor Delano, were of great aid and comfort throughout the operation.

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PART II—EVALUATION OF REQUIRED MAINTENANCE AND REPAIRS

Abstract

Two M-46 and eight M-26 medium tanks were exposed to E-shot in Operation Greenhouse. These vehicles were located at ranges of 500, 750, 1000, 1233, and 1400 yd from ground zero, with various orientations relative to the burst point.

The object of this test exposure was to determine the over-all combat effectiveness of the medium tank, complete with full operating crew. Since human crew members could not be exposed, preliminary calculations were carried out to determine the magnitude of effects considered deleterious to personnel, and suitable instrumentation was chosen to measure these effects. Particular emphasis was placed on the measurement of ionizing radiation, blast pressures, and accelerations in the fighting compartment. A separate detailed evaluation procedure was established to determine the effects on the combat vehicle itself.

The results of the test indicate that the effects on crew members are considerably more serious than those on the vehicle itself. Within those vehicles rendered unfit for combat by violent displacement, complete crew casualty is immediate. At greater ranges from ground zero, lethal radiation dosages are incurred by the crew when the medium tank suffers no impairment of combat effectiveness. The effects of blast pressures within the crew compartment are of little consequence.

Briefly the results may be given as follows:

1. Combat effectiveness of vehicle alone: 0 ~~per cent~~, 0 to 500 yd; 0 to 100 per cent, 500 to 1000 yd; 100 ~~per cent~~ at distances greater than 1000 yd;
2. Immediate combat effectiveness of crew: 0 per cent, 0 to 900 yd; 0 to 100 ~~per cent~~, 900 to 1100 yd; 100 ~~per cent~~ at distances greater than 1100 yd;
3. Delayed combat effectiveness of crew (periods greater than 24 hr): 0 ~~per cent~~, 0 to 1200 yd; 0 to 100 ~~per cent~~, 1200 to 1600 yd; 100 per cent at distances greater than 1600 yd.

These results apply specifically to existing conditions on E-shot.

Chapter 1

Introduction

1.1 COMBAT EFFECTIVENESS OF ARMOR

The combat effectiveness of armor, when the possibility of an atomic bomb attack exists, may be described by the following criteria of its employment: (1) tactical use of armor under conditions of offensive maneuvers utilizing atomic weapons, (2) tactical use of armor under conditions of defense against atomic weapons, and (3) determination of the relative effectiveness of different types of armor under conditions 1 and 2 above.

1.1.1 Tactical Offense

Military conditions may arise in which an objective becomes of great importance and the necessity of its attainment imperative. Under such conditions, an atomic attack followed by immediate occupation becomes reasonable and worthy of consideration. It is desirable, then, to know the effects of an atomic weapon on heavily armored vehicles and their crews in order to evaluate the degree of destruction experienced by the enemy, for it appears reasonable that such vehicles will suffer less than others from exposure to an atomic blast. Also it would be advantageous to know the closest point to which the attacking force might approach and those effects of an atomic explosion which offer the greatest hazard to the attacking vehicle-crew combination. It is easily visualized that heavy armor, striking soon after an atomic attack, may well keep an objective immobilized until the area has cooled sufficiently to allow ground troops to approach.

1.1.2 Tactical Defense

Essentially the arguments given in Sec. 1.1.1 apply in reverse to the determination of optimum defense tactics when an atomic bomb attack is imminent. In addition, consideration should be given to the possible shielding from thermal and nuclear radiation offered to personnel by armored vehicles.

1.1.3 Relative Effectiveness of Various Types of Armored Vehicles When Subjected to an Atomic Attack

Determination of the types of vehicles most resistive to an atomic attack is of great tactical importance. A knowledge of structural weaknesses of different types of vehicles permits modification of weak components to minimize damage to materiel and personnel.

1.2 EXPERIMENTS WITH ARMOR UNDER CONDITIONS OF ATOMIC BOMB ATTACK

1.2.1 Operation Crossroads

The first experiments with armored vehicles subjected to an atomic bomb were made in Operation Crossroads. It would be well to summarize here some of the salient features of the experiments relative to ordnance equipment. First, the results of test Baker indicate that the damage to ordnance equipment was minor and that the test was not conducted under conditions likely to be met in the field.[1] Second, the usefulness of results from test Able on light ordnance equipment was greatly reduced by the shackling of materiel to the ship decks, and again the test was not conducted under field conditions.[2] However, some useful data were obtained, and the conclusions of interest are as follows:

1. Eighty-six per cent of the damage resulted from blast pressure.

2. Mechanical damage to equipment is considered to be relatively insignificant when compared to the casualties from the physiological effect of the atomic bomb on operating personnel.

3. No lasting radiological effect on ordnance materiel occurred from the air burst.

4. The conditions of exposure were unnatural, since flying debris (dust, rocks, etc.) were absent.

5. Closed hatches on tanks will explode within 600 yd from the point of burst.

6. Inspection covers between the engine and fighting compartment will be torn loose within 1600 yd from the burst point.

7. Radio aerials of the whip type will be broken within 600 yd from the point of burst.

On the basis of these and other conclusions, it was recommended, among other things, that a new test be made over land to determine the tactical effect on military equipment and that means be taken to prevent tank-hatch and inspection-cover explosion. These recommendations were followed for the exposure of combat vehicles in Operation Greenhouse.

A few additional remarks may be made concerning the results of Operation Crossroads. In the first place, much of the ordnance materiel was shielded from direct exposure to the blast by other equipment and by the superstructure of the ship. Although this shielding has little effect on the total blast impulse, it might result in a different pressure-rise time in the blast wave, and it is quite likely that the severity of the effects on certain ordnance equipment was the result of the pressure-rise rate in the shock front. For instance, not all inspection covers were torn open violently within 1600 yd from the burst point. It is difficult at this time to assess quantitatively the shielding which might have been important in this test. The suggestion is strong, however, to arrange any future exposures in such a way that the effects of shielding may be eliminated or that these effects may be studied quantitatively.

In Table 1.1 are given the location by ships of exposure sites for ordnance equipment (Operation Crossroads) and the shielding of the heaviest items, M-26 and M-24 tanks. In Fig. 1.1 the peak overpressure as a function of distance from the burst point is given for test Able, Operation Crossroads.[3]

1.2.2 Operation Sandstone

No ordnance equipment was exposed in Operation Sandstone for the sole purpose of determining the effects on such equipment. However, certain general phenomena were observed from which guesses could be made as to possible damage occurring to heavily armored equipment under field conditions. For instance, large quantities of dust were carried at high velocities by the shock wave, and surfaces having poor resistance to abrasion were injured. Optical equipment on ordnance vehicles, such as a periscope on a tank, would probably suffer damage which would impair the immediate combat usefulness of the vehicle.

Considerable data on blast pressures and nuclear radiation fluxes were obtained on Sandstone which make it possible to calculate roughly the damage to heavy ordnance equipment and enclosed combat crews at various distances from an atomic bomb burst. Unfortunately, these calculations are only approximate, but they do indicate in a general sense the expected effects.

1.3 DECISION TO ASSIGN PROBLEM OF DETERMINING EFFECTS OF ATOMIC WEAPONS ON ARMORED EQUIPMENT TO THE ARMY ORDNANCE CORPS

A meeting was held at the Office, Chief of Ordnance, Aug. 5, 1949, to discuss a proposal from the Department of the Army for the exposure of various materiel in the 1951 atomic bomb tests. Present at this meeting were representatives from the various technical corps of the Army, as well as personnel from the Operation Research Office and the Armed Forces Special Weapons Project. It was decided that the Ordnance Corps should prepare a proposal for the exposure of various materiel at the coming tests. This proposal was to be given to the Research and Development Division, Department of the Army, General Staff, for presentation to the Joint Chiefs of Staff as the proposal for the Army participation. Subsequently, this proposal was accepted, with certain modifications, and the Ordnance Corps was assigned the responsibility for certain phases of the program.

TABLE 1.1 POINTS OF EXPOSURE OF HEAVY ORDNANCE EQUIPMENT
(Operation Crossroads)

Location	Distance from Burst (yd)	Shielding, M-26	Shielding, M-24
Arkansas	600	Yes	Yes
Nevada	600	Partially	Yes
Pennsylvania	1600	Yes	No
Saratoga	2300	No	No

In December 1949, work was begun on organizing two separate groups of the Ballistic Research Laboratories (BRL), Aberdeen Proving Ground, to consider, separately, the over-all effect of atomic weapons on heavily armored vehicles and the thermal effects of the atomic bomb on the various materials used by the different branches of the Army. It soon became apparent that the thermal-effects portion of the program involved all the Department of Defense; and, for the sake of coordination and because of personnel distribution, responsibility for over-all cognizance of this portion of the program was assigned to the Naval Radiological Defense Laboratory. That part of the original program pertaining to the effects on armored vehicles remained unchanged and under the cognizance of the Ordnance Corps.

1.4 DECISION TO CONSIDER THE EXPOSURE OF ONE TYPE OF HEAVY ORDNANCE EQUIPMENT RATHER THAN SEVERAL DIFFERENT TYPES

The exposure of the various types of ordnance equipment at Operation Crossroads showed clearly that only general conclusions could be drawn because of the small numbers of each type exposed.

The planning for exposure of armored vehicles for Operation Greenhouse was based on a premise entirely different from that of the exposure of groups of materiel of all types. This premise was that if the correlation between theoretical and experimental results can be determined for one vehicle then extrapolation to other types of vehicles may be attempted with some degree of confidence. Where calculated and experimental results show the greatest divergence, further limited experiments may be conceived to resolve the difference.

On the one hand, the larger the statistical sample, the more valid is the comparison between experimental and theoretical results. On the other hand, the physical size of heavy ordnance equipment and the difficulty of transporting it impose a limitation on the number of samples which may be used.

From these considerations, it was concluded that exposure of one type of vehicle, well instrumented, should yield a greater amount of useful information than the exposure of several different types with the same total weight.

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1. Final Report of Atomic Bomb Tests, Jan. 27 to Sept. 30, 1946, Vol. IV, Appendix VII, Report of Commander, Task Unit 1.4.3 (Ordnance).
2. Ibid., p 8.
3. Sandstone Report, Annex 5, Vol. 20, "Blast Measurements Summary Report."

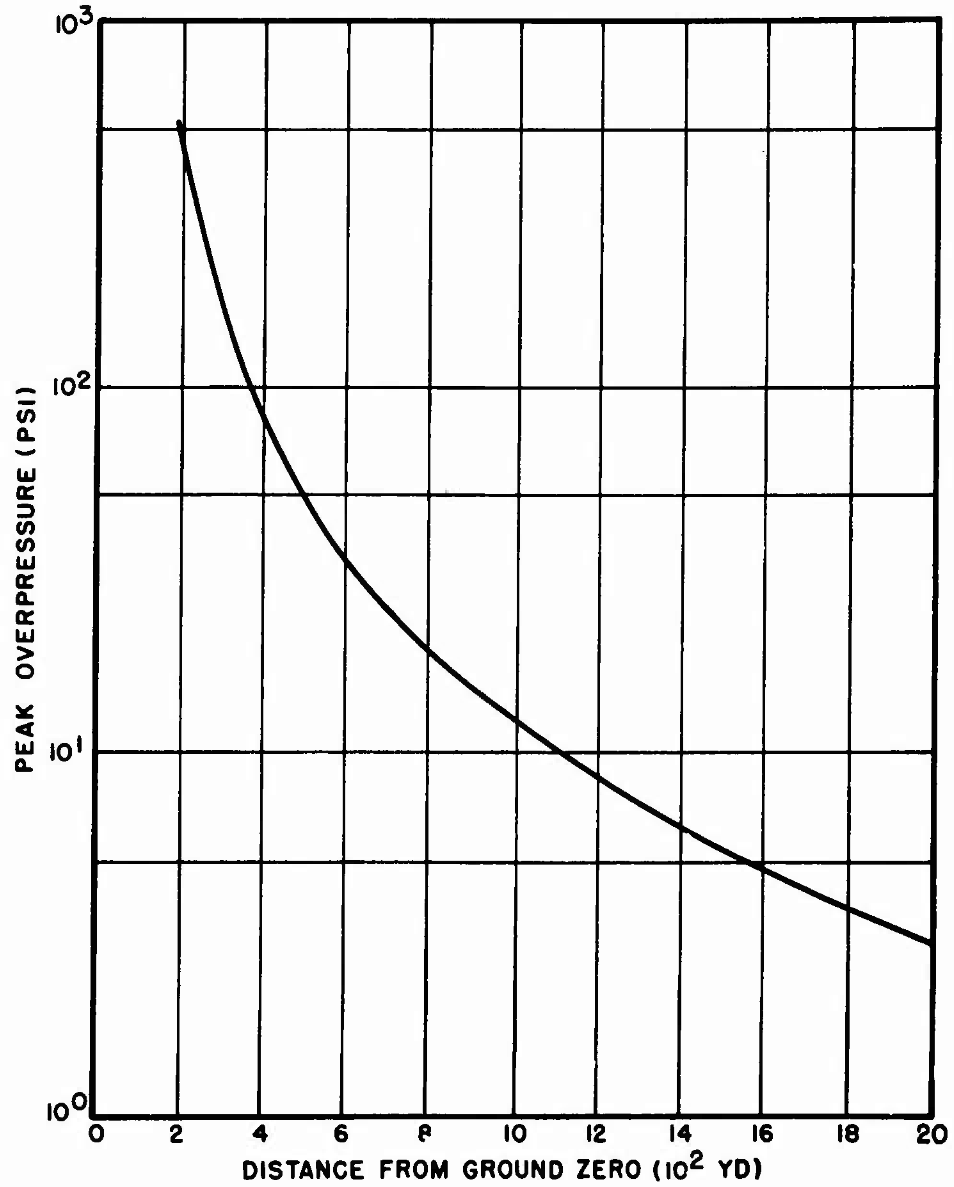

Fig. 1.1 Peak Overpressure vs Distance, Bikini Able

Chapter 2

Phenomena Affecting Use of Combat Vehicles During and Following Atomic Weapons Attack

2.1 EFFECTS ON PERSONNEL

2.1.1 Nuclear Radiation

In the exposure of combat vehicles in Operation Crossroads, no attempt was made to instrument the interior fighting compartments of the various vehicles. As a result, the only conclusions which could be drawn from the exposure were those pertaining to combat effectiveness exclusive of the operating crew. This lack of instrumentation was unavoidable in view of the conditions under which the test was made, but the fact remains that such omission made a subsequent exposure necessary so that interior data could be obtained.

The nuclear radiation resulting from an atomic bomb detonation is a phenomenon having little lasting effect on a tank (from this point on the discussions will consider the tank as representing heavily armored vehicles) because of the negligibly small amounts of tank materials in which radioactivity may be easily induced. This statement is probably true for vehicles exposed beyond a 300- to 400-yd distance from a nominal atomic bomb explosion. To the crew, buttoned-up inside the vehicle, the presence of nuclear radiation probably constitutes the most serious aspect of an atomic explosion. Data from gamma-ray-shielding experiments on Operation Sandstone[1] and predictions of roentgen dosages vs distance for a 50-kt bomb[2] show that an average shielding thickness of 4 in. of steel (average shielding within an M-26 tank) would result in lethal to median-lethal dosages out to 1200 yd from the burst point of such a bomb. The lethality of neutron fluxes within the fighting compartment of a tank is difficult to evaluate. The shielding geometry is very complicated, and the spectral energy distribution of the neutrons is not well known. At best, the Sandstone results[3] can be applied qualitatively, and it can be stated that within the fighting compartment the reduction (compared to outside values) in fast-neutron fluxes may be of the order of 50 per cent. The fast neutrons here are those detectable by sulfur (>3 Mev), whereas the slow neutrons are those detectable by arsenic. The obvious gaps in the data necessitate the usage of the word "qualitative" in all discussions of expected neutron fluxes as far as effects on personnel are concerned.

2.1.2 Accelerations

The sharp pressure rise at the forward boundary of the shock wave produced in the atomic explosion is capable of imparting large accelerations to heavy pieces of equipment, such as tanks, even though the distance moved by these items may not be great. These large accelerations constitute a serious hazard to the combat crews within a tank, if no precautionary measures have been taken. Large pieces of equipment within the fighting compartment may be torn loose, and members of the combat crew may be tossed against various tank components. An evaluation of possible accelerations is therefore necessary, if effects on combat crews are to be considered.

2.1.3 Thermal Radiation

Almost one-third of the energy released in an atomic explosion appears as ultraviolet, visible,

and infrared radiation. Ordinarily, geometrical shielding (shielding by an object through which these radiations cannot pass) is sufficient to protect personnel from this aspect of an atomic bomb. In the case of a tank, however, a great deal of this radiation is absorbed in the outer layers of armor of the vehicle, and, if lateral conduction of the resultant heat is not rapid, the inner surface of the tank walls may be heated to a point injurious to personnel coming into contact with it immediately after exposure. Of course, this effect is dependent upon many factors. If the burst point of the bomb occurs above the roof of a tank, the flat, relatively thin roof conducts laterally at a slow rate and permits a large temperature rise on the inner surface. The incident radiation, however, is conditioned by other shielding (dust, trees, etc.) and the yield of the weapon. For a burst low on the horizon, the incident radiation strikes a thicker portion of the armor of the vehicle, and the amount of heat conducted laterally through the shell is sufficient to prevent any large temperature rise on the inner surfaces. Under such conditions the thermal effects on the combat crew would be neglibible, if the vehicle were completely closed.

2.1.4 Blast Pressures and Temperatures

Within a completely closed (buttoned-up) tank the physiological damage caused by shock-wave overpressures and heating of the air by shock-wave passage would probably be quite small. The vehicle is by no means airtight, but the ratio of the total orifice area, through which particles may flow, to the volume of the fighting compartment is fairly small, and the pressure-rise rate is consequently much smaller. In addition, the orifices are quite complicated; so compression within the tank would probably occur adiabatically, and large temperature rises would not take place. However, if the vehicle hatches are open (not buttoned-up), pressure and temperature rises would closely approximate those outside, and the combat crew might then suffer from ruptured ear drums, etc. Even under the worst conditions, however, the effects of blast and temperature rise in the shock front would be of little importance compared to the effects from nuclear radiations.

2.2 EFFECTS ON MATERIEL

As has been mentioned previously, the effect of an atomic burst on a heavy combat vehicle is small when compared to effects on combat-crew personnel. However, the effects on materiel are important in the over-all picture. For planning and development purposes it is necessary to know what effort would be required to restore vehicles subjected to atomic attack to minimum combat effectiveness.

Within the Department of Defense are three recognized echelons of maintenance: (1) organizational maintenance (refueling, water check, tire change, greasing, adjustments, minor assembly replacements, etc.), (2) field maintenance (major assembly replacements, minor overhaul, etc.), and (3) depot maintenance (major overhaul, complete reconditioning, etc.). Following an atomic bomb attack, the division of the affected vehicles into the various categories of maintenance required to restore them to minimum combat effectiveness indicates to a large extent the usefulness of such vehicles. The limited number of samples exposed at Greenhouse makes it meaningless to attempt predictions of individual component failures, and, at best, the test may indicate only obvious weaknesses in the armored equipment of this type of weapon.

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1. E. J. Hoffman, E. C. Vicars, and H. Scoville, Jr., Gamma Radiation Shielding, Task Group 7.6 Project Report, Project 7.1-17/RS (BS)-2, Figs. 1 to 4.
2. Handbook for Biological Experimenters at the 1951 Eniwetok Tests, Los Alamos Scientific Laboratory, Los Alamos, Fig. 16.
3. H. Scoville, Jr., H. L. Andrews, E. J. Hoffman, and E. C. Vicars, Neutron Absorption, Navy Task Group 7.6 Project Report, Project 7.1-17/RS-6, p 1.

Chapter 3

Theoretical Approach to the Problem

3.1 EFFECTS ON PERSONNEL

3.1.1 Nuclear Radiation

The problem, stated briefly, is to determine the total roentgen dosage experienced by tank-enclosed combat-crew personnel at various distances from an atomic bomb burst. This total dosage is the sum of the ionization caused by direct gamma reactions and the induced neutron reactions, disregarding alpha carriers and the induced beta activity in the vehicle armor.

The complex geometry of a combat vehicle, as a scatterer of gammas and neutrons, prevents a practical theoretical solution for interior dosages, even when exterior fluxes are completely known. The best that can be done under such circumstances is to make simplifying assumptions and attempt to estimate interior dosages within an order of magnitude. These estimates may then be used to establish the types of instrumentation most suitable for measurements in laboratory and field experiments.

The thickness of armor shielding around the fighting compartment ranges approximately from 1 to 7 in. of steel, with an average thickness of perhaps 4 in. The thinnest portions are found in the roof and floor of the vehicle; so interior roentgen dosages, arising from gamma radiation alone, will depend on the position of the bomb, assuming directional characteristics of the radiation relative to the vehicle.[1] For a shielding thickness of 4 in. and an average gamma energy[2] of 4.5 Mev, it is possible to estimate the roentgen dosage inside the combat vehicle. From a report by Plesset and Cohen[3] an expression for roentgen dosages behind a heavy metal shield is obtained.

$$r = 0.727 \cdot 10^{-5}\ \mu_A\, \alpha_0 E_0\, B(x) \exp(-\mu_T\, \alpha_0 x) \qquad (3.1)$$

where r = roentgen dosage behind the plate
μ_A = absorption coefficient in air
α_0 = energy of photon
$E_0 = \alpha_0 I_0$ = incident energy per unit area
$B(x)$ = weighting factor (>1) which accounts for scattering effects in thick absorbers and is a function of the atomic weight
μ_T = total absorption coefficient in metal shield
x = thickness of the metal shield in centimeters

Another expression has been derived for the transmitted dosage in air r^t at some distance d from a known dosage in air.[4] This expression is

$$r^t d = 0.727 \times 10^{-5}\ \mu_A\, \alpha_0 E^t d \qquad (3.2)$$

The quantities E_0 and E^t in Eqs. 3.1 and 3.2 are identical; therefore

$$r = r^t\, B(x) \exp(-\mu_T \alpha_0 x) \qquad (3.3)$$

or

$$0 = x + (1/\mu_T \alpha_0) \ln [r/r^t\, B(x)] \qquad (3.4)$$

Equation 3.3 permits a computation of interior dosages from exterior data, whereas Eq. 3.4 is convenient for calculation of shielding thicknesses required for desired dosage-reduction ratios, r/r^t. Using approximate values of B(x) and the proper value[5] for μ_T at 4.5 Mev, it is possible to compute expected interior dosages at various distances from the burst point for the expected yield of a 50-kt bomb.[6]

The expected interior dosages as a function of distance from the burst point are given in Fig. 3.1. These data are not very reliable because of the assumptions made; however, for the purpose of instrumentation planning, they are sufficiently accurate.

In Sec. 2.1.1 the statement was made that within the fighting compartment the reduction in slow- and fast-neutron fluxes was small for the former and approximately 50 per cent for the latter. This statement was qualitative. In a previously cited reference[7] it is pointed out that 2 in. and 6 in., respectively, of steel on all sides are necessary to reduce by a factor of 2 the fast- and slow-neutron fluxes. However, this conclusion is not sufficiently different, for the purposes of instrumentation or the estimation of lethal neutron ranges, from the earlier statement, and no attempt was made to compute expected neutron fluxes inside the tank.

3.1.2 Accelerations

The computation for acceleration experienced by a tank, or any other combat vehicle, is made very difficult by the highly irregular surface over which the shock wave passes. Other effects arising from the shock-wave passage are also of considerable interest, viz., the maximum velocity attained and the displacement of the vehicles as a function of distance from the burst point.

Maximum velocities and displacements were obtained from pressure-time curves computed by the Ordnance Engineering Laboratory, BRL. Shock-tube interferograms[8] made at shock overpressures of about 14 psi acting on a 1-in.-high rectangular block were used to estimate the shock pressures at the tank surface. Two scaling factors were utilized in converting the model pressure-time curves to the full-scale tank conditions: (1) a time scaling factor equal to the ratio of the tank dimensions to the dimensions of the model used in the shock tube and (2) a pressure scaling factor equal to the ratio of the side-on pressure of the decaying shock wave, at any scaled time, to the side-on pressure of the plane shock wave studied in the shock tube.

With the peak overpressure and duration of the decaying shock known, the shock pressure-time curve was plotted using Friedrichs's equation.[9] Pressures on the front and rear faces of the tank were then deduced by means of scaling the model pressures. The final pressure-time curve represents the difference between front and rear pressure on the tank as calculated by this method. The reflected pressure is of such short duration that its effect was neglected. Using a drag coefficient of unity, the calculated aerodynamic drag-pressure curve joins the pressure-difference curve with a good fit.

The total impulse, producing motion of the tank, was found by integrating the pressure-difference curve (pressure difference between front and rear faces of the tank) after subtracting the frictional force. That is

$$I = A \int_{t_0}^{t_1} (p - f)\, dt \qquad (3.5)$$

where I = total acting impulse
A = projected area of the tank
p = pressure difference between front and rear faces
f = frictional force per unit projected area
t_0 = time of shock onset
t_1 = time at end of positive phase (it was found that the negative phase contributed nothing to the motion)

The maximum velocity of the tank was computed from the equation

$$I = MV_m \qquad (3.6)$$

where M = mass of the tank and V_m = maximum velocity attained. The total distance moved can be found from the equation

$$FS = \frac{MV_m^2}{2} \qquad (3.7)$$

where F = total frictional force and S = total displacement.

From Eqs. 3.5 to 3.7 the total impulse, maximum velocity, and total displacement for head- and side-on orientations were computed for various distances from the burst point. These data are presented in Figs. 3.2 to 3.4.

The maximum acceleration experienced by a rigid object is probably very close to the force arising from the reflected pressure divided by the mass of the vehicle. The high accelerations

thus obtained may be real but are not significant because of their transient nature. The maximum accelerations were computed, however, using the reflected-pressure values[10] corresponding to expected peak overpressures for a 50-kt explosion.[11] These values are probably greater than those recorded because of time-response limitations of the instrumentation, but the values serve as upper limits for instrument specifications. Expected maximum accelerations for head- and side-on exposures are given in Fig. 3.5 as a function of distance from the bomb.

3.1.3 Thermal Radiation

It was stated that a bomb bursting low on the horizon, with the accompanying dust-cloud obscuration, would not result in appreciable temperature rises on the inner surface of the tank wall. However, to obtain a qualitative indication of the maximum possible temperature rise, certain computations were made. The assumptions on which these computations were made are as follows:

1. Any increase in the temperature of the vehicle during the 4 sec following detonation is due to thermal-radiation interchange alone.
2. Heat transfer by conduction and convection from the heated walls of the tank into the surrounding air is neglected.
3. Heat loss by reradiation from the outermost surface of the tank wall is small compared to inward conduction through the metal.
4. The reflection coefficient of the tank's outer surface is small.

These four assumptions appear to restrict the analysis to a point of uselessness. However, considering the surface material of the tank and the maximum temperature rise at the surface, some results are obtained which have qualitative significance.

The simplest calculation which can be made is the temperature rise in a cylinder of unit cross section and length equal to the thickness of the tank wall. If this small cylinder is taken at the center of the irradiated section of the tank wall, the flow of heat through the walls of the cylinder will be negligible, and only the one-dimensional flow need be considered. Further, the loss of heat by the tank wall through processes of convection and conduction at the air interfaces is very small compared to conduction into the metal. Therefore if the total heat flux Q, delivered at some distance from the bomb, is assumed to be absorbed by the tank wall, the rise in temperature will be given by the expression

$$T = T_0 + \frac{Q}{V\rho C} \tag{3.8}$$

where V = volume of the cylinder
ρ = density of material
C = heat capacity of the material

By utilizing the data on heat delivery for a nominal atomic bomb[12] and by multiplying by a scaling factor of 2.5 for a 50-kt equivalent charge, the total heat delivered as a function of distance from charge is obtained. Neglecting the atmospheric absorption of radiation gives an upper limit for the values. Total heat deliveries are plotted in Fig. 3.6 as a function of distance from the detonation point. By assuming that all the heat delivered is absorbed in the tank wall, it is possible to compute the temperature rise at the inner surface of the tank wall by means of Eq. 3.8, where the values for ρ and C are taken as 7.75 g/cc and 0.118 cal/g/°C, respectively. Temperature rise is plotted in Fig. 3.7 as a function of heat delivered for various slab thicknesses. These data give, of course, the upper limit of possible temperature rise at the inner surface of the tank wall.

Unfortunately, the problem is one of unsteady heat flow complicated by the fact that the rate of thermal-radiation delivery is not constant. This complication is not too serious, however, since the total time of irradiation is of the order of 4 sec and since normal conduction processes are concerned with somewhat longer times. The net result of a variable rate of delivery is only a slight change in the final temperature obtained in the tank wall, but probably a significant difference, from constant rate of delivery effects, in the maximum temperature at the outer surface of the tank wall. One aspect of the heat flow in metals which has been thoroughly studied both experimentally and theoretically is the temperature rise of slabs or other geometrical shapes exposed within a heating furnace. By analogy, a tank wall exposed to an atomic explosion will undergo a temperature rise similar to that of a metal slab placed suddenly in a furnace, if the furnace

temperature is so adjusted that heat flux at the slab surface is the same as the net radiation flux at the tank's outer wall and if the slab is twice as thick as the tank wall (the slab is heated on two sides in the furnace). This analogous method of determining surface and interior temperatures in the tank wall is simple, since tables for computing temperature rise in metal slabs have already been worked out[13] and may readily be applied to this problem. The details of the computational procedures are beyond the scope of this report. In Fig. 3.8 are plotted expected maximum temperatures at the outer tank-wall surface as a function of distance from the burst, using the heat-delivered data in Fig. 3.6.

One other computation is of interest, since the assumption has been made that reradiation from the outer tank surface need not be considered in the net heat interchange in the tank wall. The total heat flow from a thin section of the outer tank wall of unit cross section in a time dt is given by

$$\frac{dQ}{dA} = dt\left[\sigma(T_s^4 - T_A^4) + kx\,\frac{dT}{dx}\right] \tag{3.9}$$

where T_s = temperature of the outer surface of tank wall

T_A = effective black-body temperature[14] of the atmosphere at time of firing (285°K)

kx = conductivity of steel

$\frac{dT}{dx}$ = slope of the temperature curve

σ = Stefan constant (1.35×10^{-12} cal/sq cm/sec/deg^4)

The numerical values for the two heat flows on the right-hand side of Eq. 3.9 indicate the relative effectiveness of these two forms of heat dissipation for a given temperature distribution within a slab of metal. By methods already mentioned,[13] a temperature distribution within a 4-in. slab of metal was calculated for simulated conditions at 500 yd for a 50-kt bomb. At the end of the period of irradiation, the surface of the metal was allowed to cool by reradiation and one-dimensional conduction into the metal. In Fig. 3.9 are shown the heat-flow values for the two processes of heat dissipation of the tank's outer surface as a function of surface temperature. Throughout the computations for temperature rise in the tank wall, a one-dimensional flow was considered applicable. If the irradiated surface is thin and flat, the assumption is good. If the surface is thick and appreciably curved, lateral conduction becomes important, and the given estimates of temperature rise are much too high.

3.1.4 Blast Pressures and Temperatures

If the assumption is made that the pressure and temperature rises inside a closed tank take place adiabatically (openings into a buttoned-up tank are very complex, and the developing of clearly defined shock waves inside the vehicle seems unlikely), it is possible to compute such rises in a fairly simple manner. Let the following terms be defined:

C = velocity of sound

ρ = atmospheric density

p = atmospheric pressure

T = absolute temperature

U = velocity of particle flow

V = interior volume of the medium tank

A = total areal opening through which particles may flow into the buttoned-up tank

t = time after onset of the shock wave

t_1 = duration of the positive phase

γ = ratio of the specific heats for air

Unfortunately, it is not possible to solve for p_i explicitly as a function of time from Eqs. 3.10 to 3.15. It is necessary to compute p_i by a step-time integration with the boundary conditions (at t = 0)

$$U_N = U_{s'} \qquad \rho_i = \rho_0$$
$$p_i = p_0 \qquad T_i = T_0$$

The values for p'_s, U'_s, and t_1 have already been determined,[16] and the values for $\rho_{s'}$ may be obtained from the Rankine-Hugoniot relations.

The method given here for calculating interior temperature and pressure rises is obviously oversimplified. No account is taken of orifice effects, with the result that computed values are probably too high. It is felt, however, that the method is justified where the aim is to determine suitable instrumentation ranges. In Figs. 3.10 and 3.11 are indicated the expected interior pressure-time and temperature-time curves, respectively, for a buttoned-up M-26 tank at 500 yd from ground zero.

3.2 EFFECTS ON MATERIEL

At the moment there seems to be little possibility of predicting, from theoretical considerations alone, the effects of the bomb on various components of a structure as complex as a medium tank. With reasonable care it might be possible to calculate shear effects on the load suspension and the stresses on various flat surfaces of the vehicle. However, such computation could hardly lead to a description of damage categorically defined as in Sec. 2.2. It seems, rather, that more experimental data are necessary before those items which are most critical in determining the combat effectiveness of a tank, or any other piece of equipment for that matter, can be investigated intelligently.

Subscripts s, s', 0, i, and N refer to conditions in shock wave, shock front (peak shock values), preshock air, tank interior, and net resultant flow, respectively.

The equations which govern the rise of pressure and temperature within the tank interior are given by

$$(p_s - p_i) = p_0 \left\{1 + \left[\frac{(\gamma - 1)}{2}\right] \times \left[\frac{(U_N - U_0)}{C_0}\right]\right\}^{[2\gamma/(\gamma - 1)]} \qquad (3.10)^{15}$$

$$p_s = p_{s'} (1 - t/t_1) \exp(-t/t_1) \qquad (3.11)^{9}$$

$$\rho_s/\rho_{s'} = (p_s/p_{s'})^{1/\gamma} \qquad (3.12)$$

$$\rho_i = \rho_0 + \Delta\rho = \rho_0 + (A/V)\rho_s U_N \, \Delta t \qquad (3.13)$$

$$p_i = p_0 (\rho_i/\rho_0)^{\gamma} \qquad (3.14)$$

$$T_i = T_0 (\rho_i/\rho_0)^{\gamma - 1} \qquad (3.15)$$

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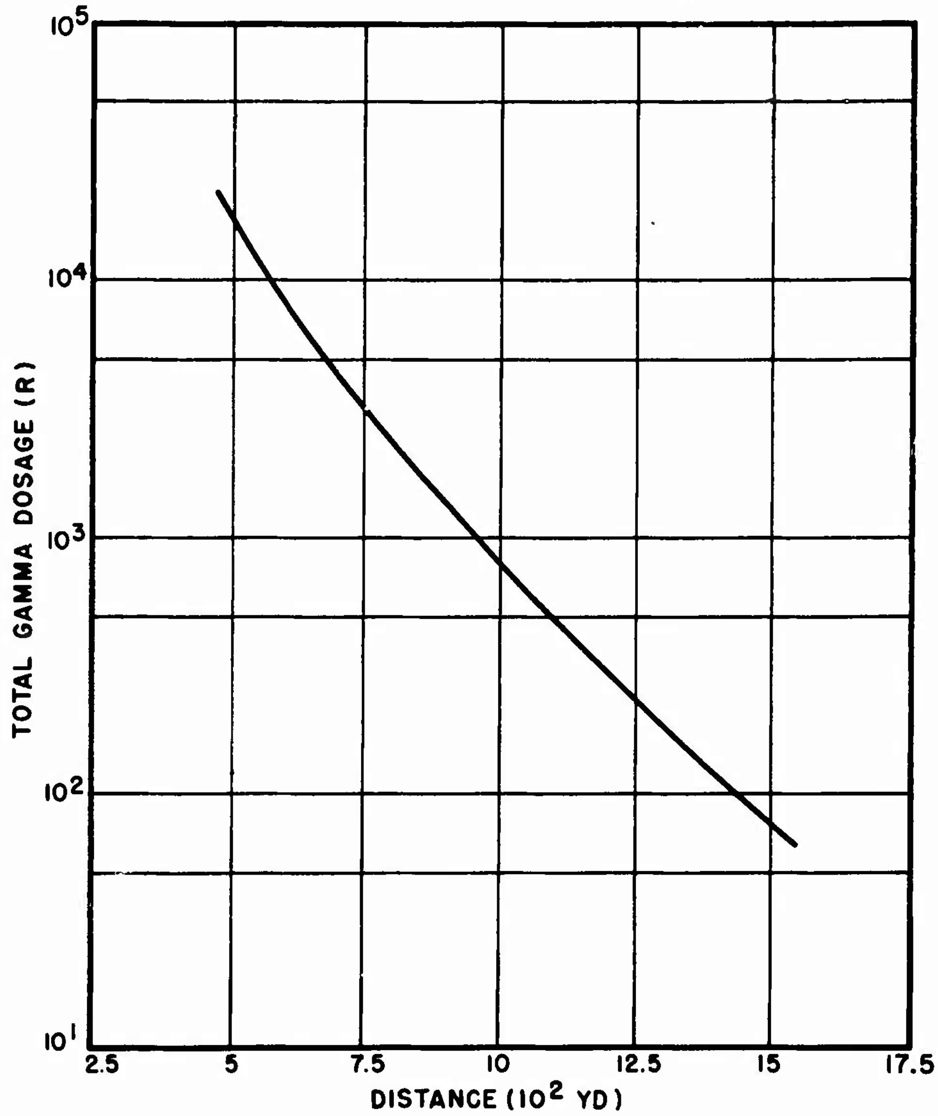


Fig. 3.1 Expected Interior Dosage vs Distance from Ground Zero

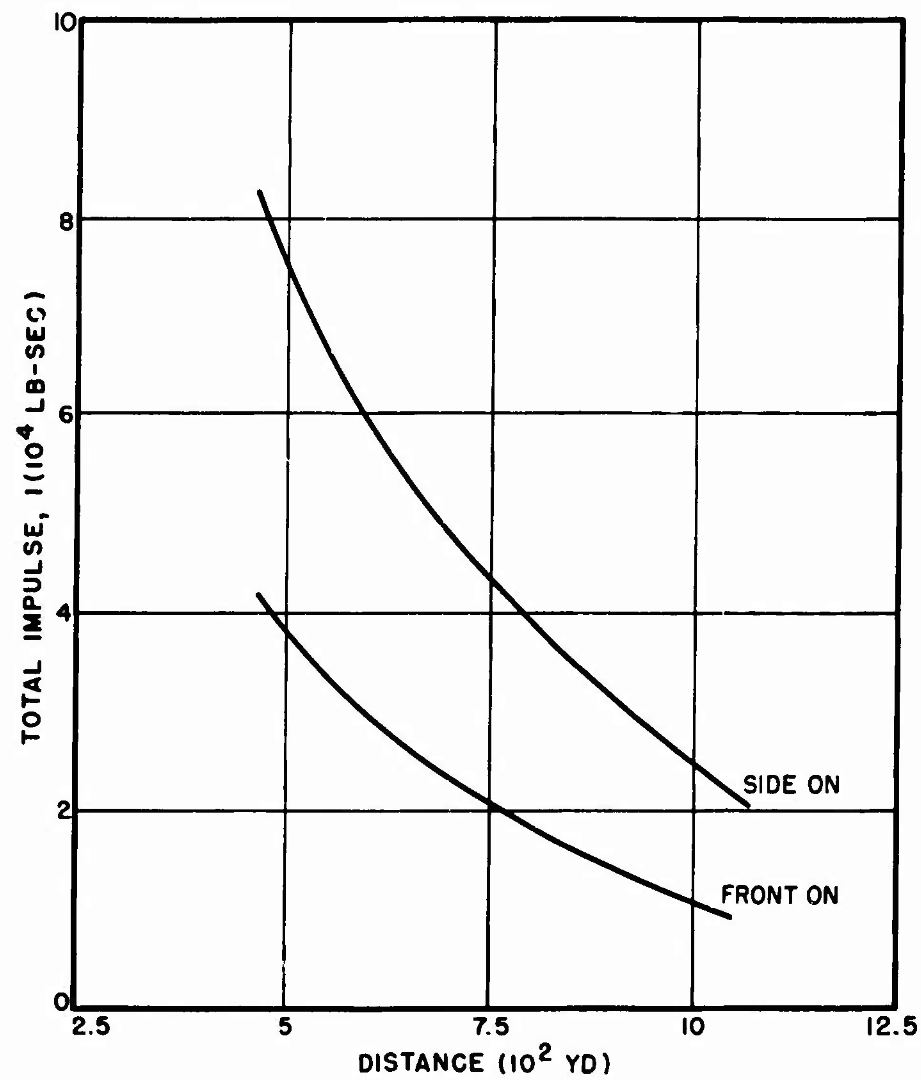


Fig. 3.2 Effective Impulse on an M-26 Tank (Side and Front Exposure) as a Function of Distance from Ground Zero for a 50-kt Bomb

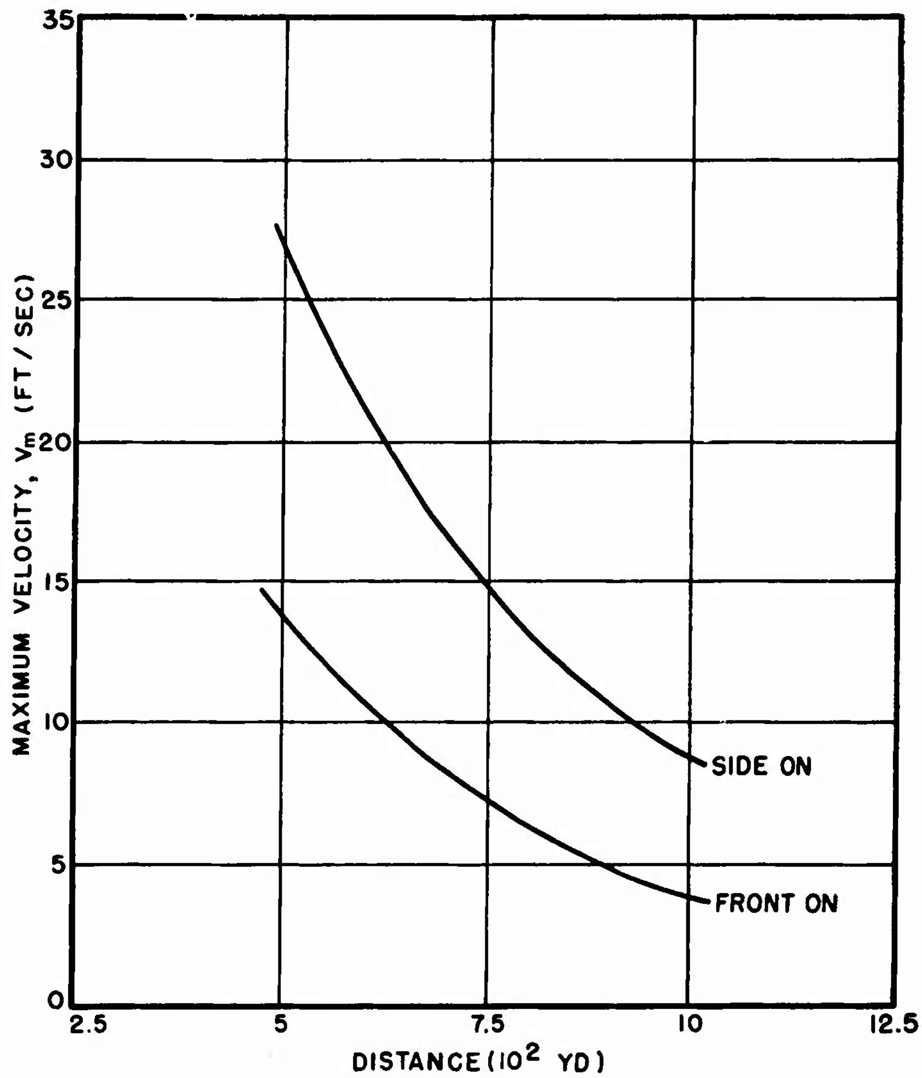


Fig. 3.3 Maximum Velocities for an M-26 Tank (Side and Front Exposure) as a Function of Distance from Ground Zero for a 50-kt Bomb

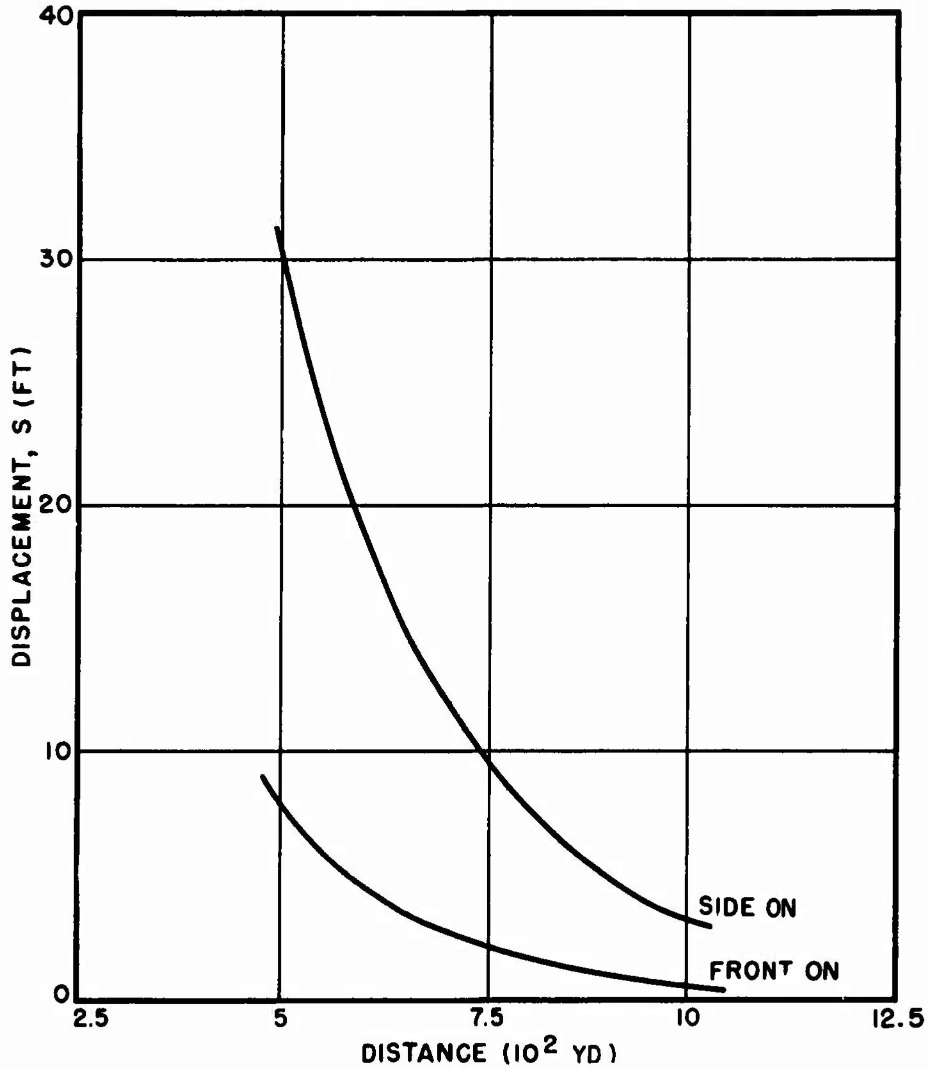


Fig. 3.4 Displacement of an M-26 Tank (Side and Front Exposure) as a Function of Distance from Ground Zero for a 50-kt Bomb

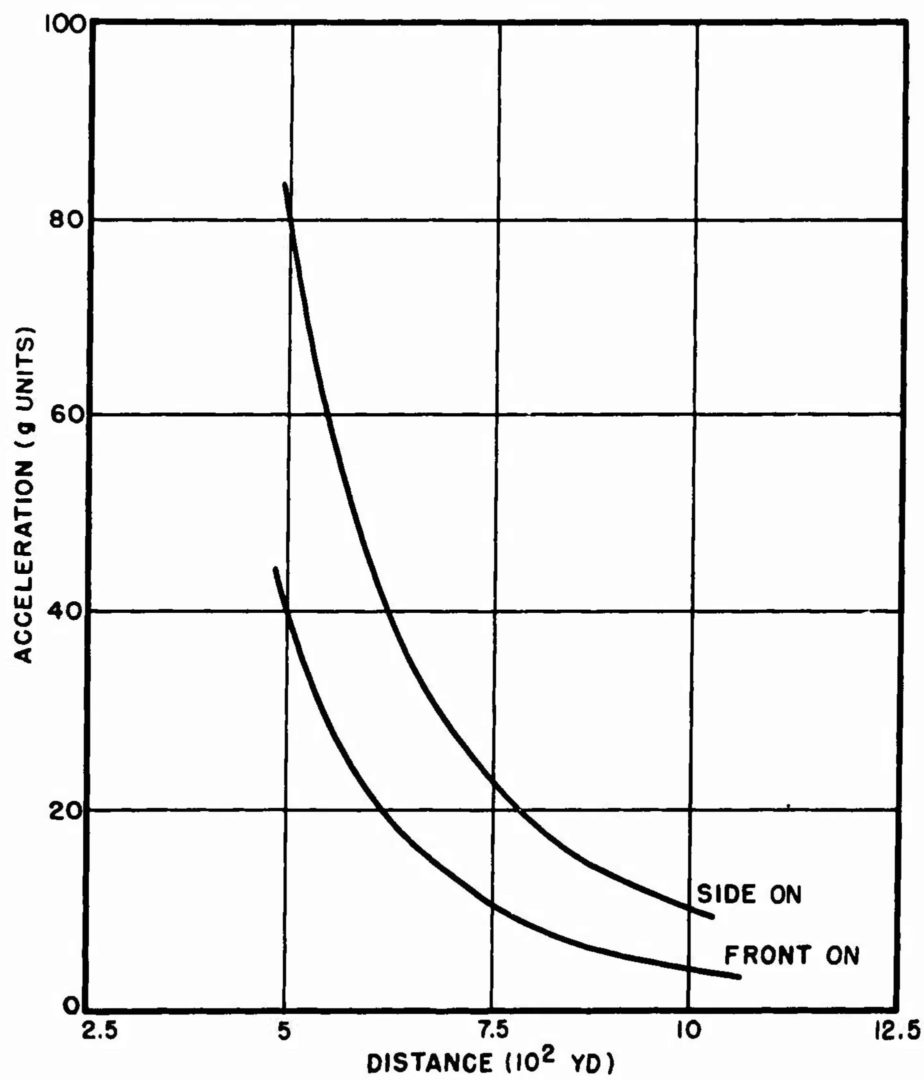


Fig. 3.5 Maximum Acceleration of an M-26 Tank (Side and Front Exposure) as a Function of Distance from Ground Zero for a 50-kt Bomb

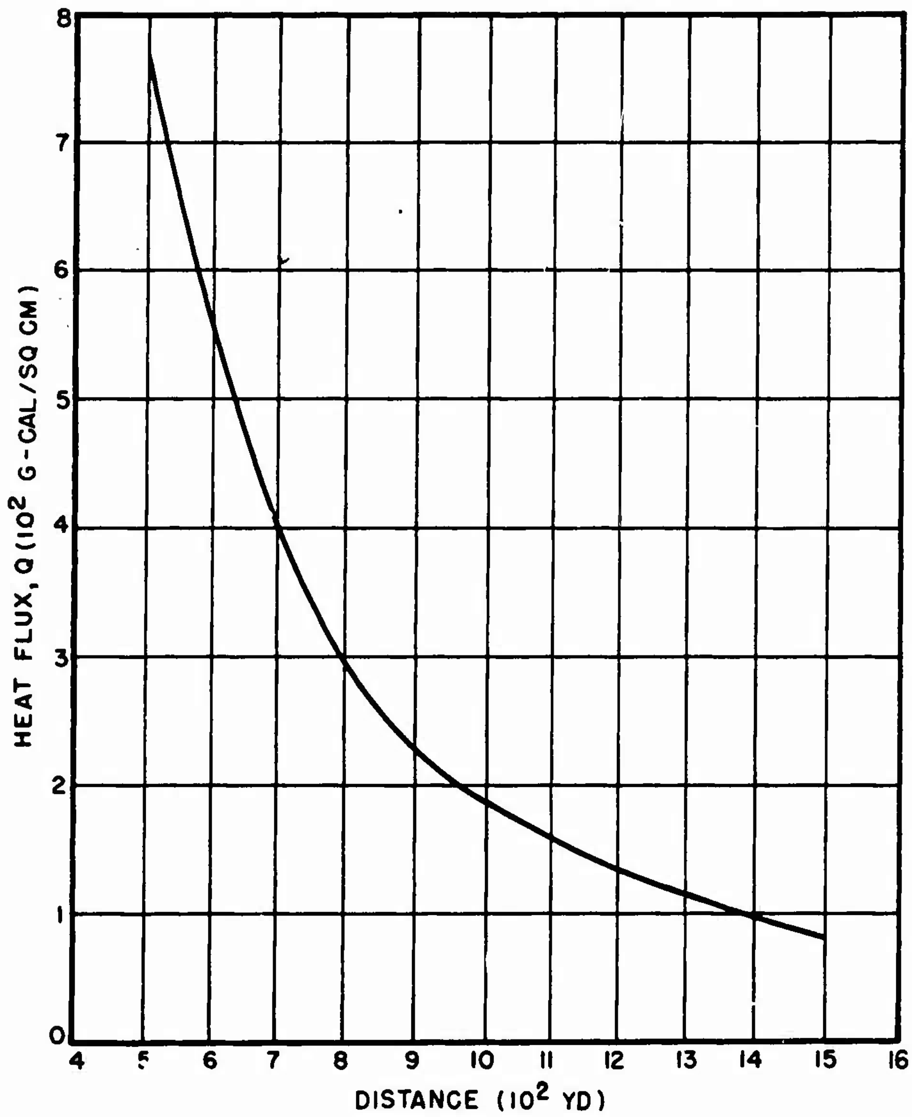


Fig. 3.6 Total Heat Flux per Unit Area as a Function of Distance from Ground Zero for a 50-kt Bomb (No Atmospheric Absorption Considered)

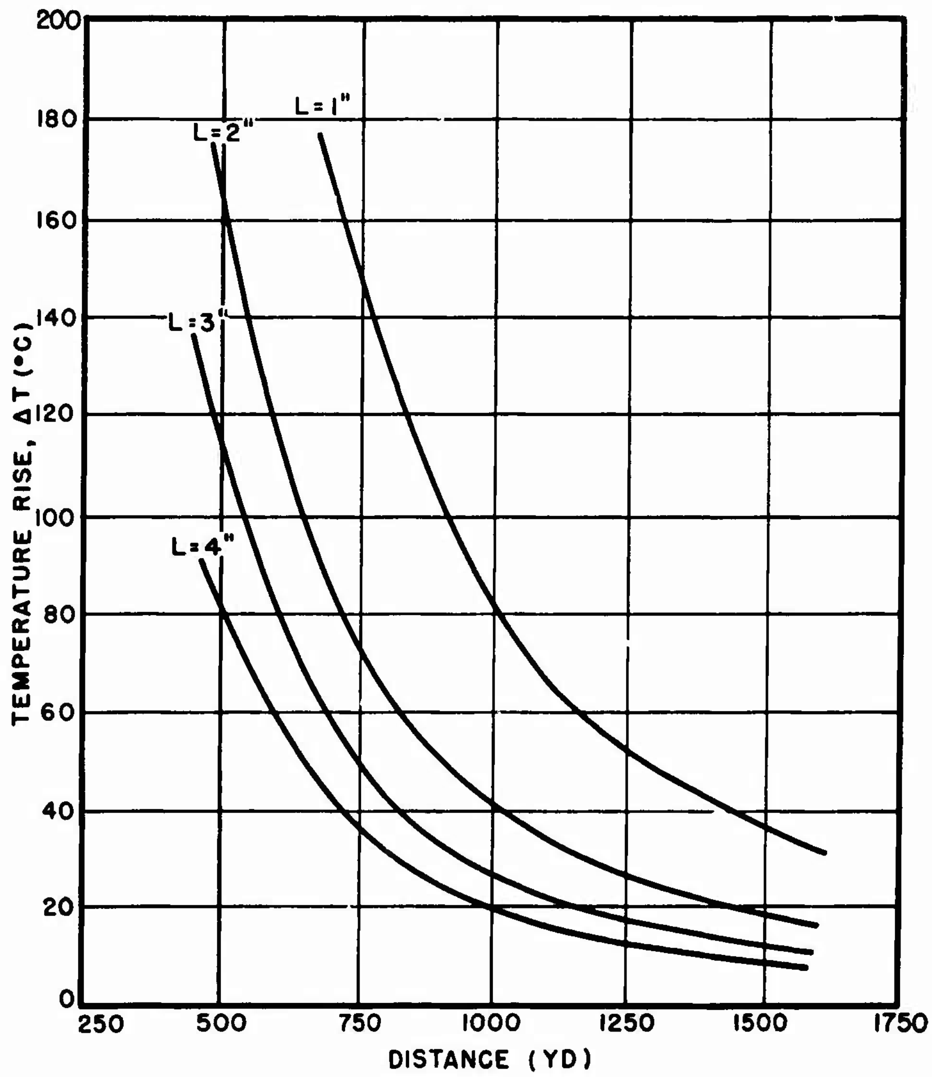


Fig. 3.7 Temperature Rise in Metal Slabs of Various Thicknesses (L) as a Function of Distance from Ground Zero for a 50-kt Bomb, Assuming All Incident Thermal Energy To Be Absorbed

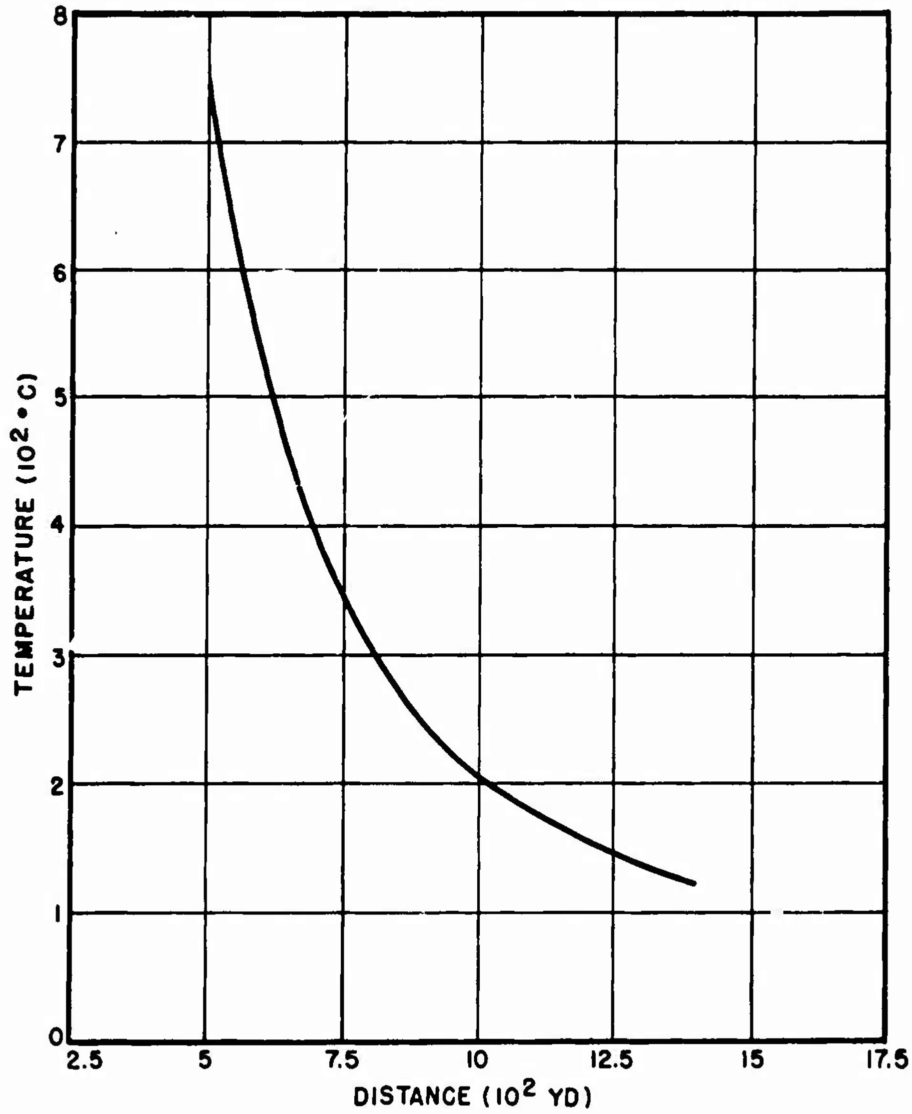


Fig. 3.8 Maximum Expected Surface Temperatures in a Tank Wall at Various Distances from Ground Zero for a 50-kt Bomb, Assuming All Incident Thermal Radiation To Be Absorbed

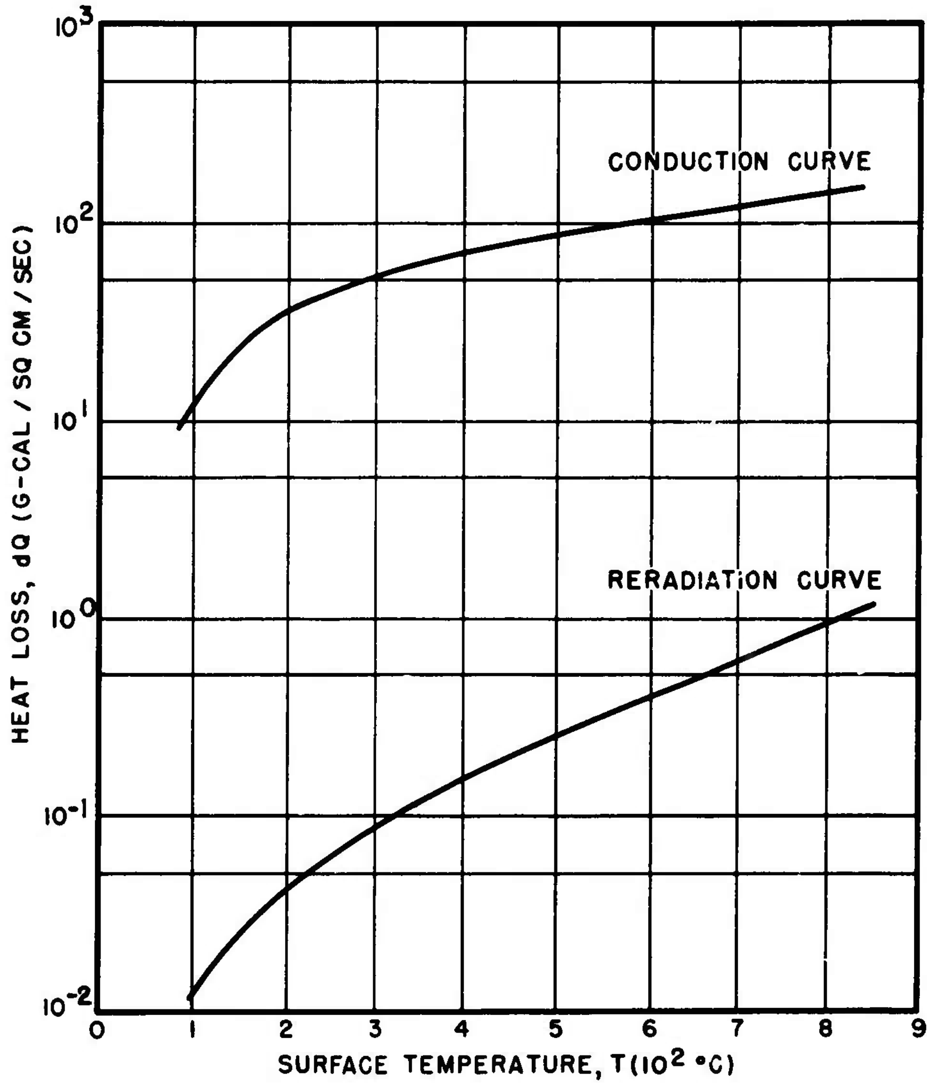


Fig. 3.9 Heat Losses from Outer Surface of an M-26 Tank Wall by Processes of Reradiation and Conduction at 500 Yd from Ground Zero for a 50-kt Bomb (Data Given as a Function of Surface Temperature)

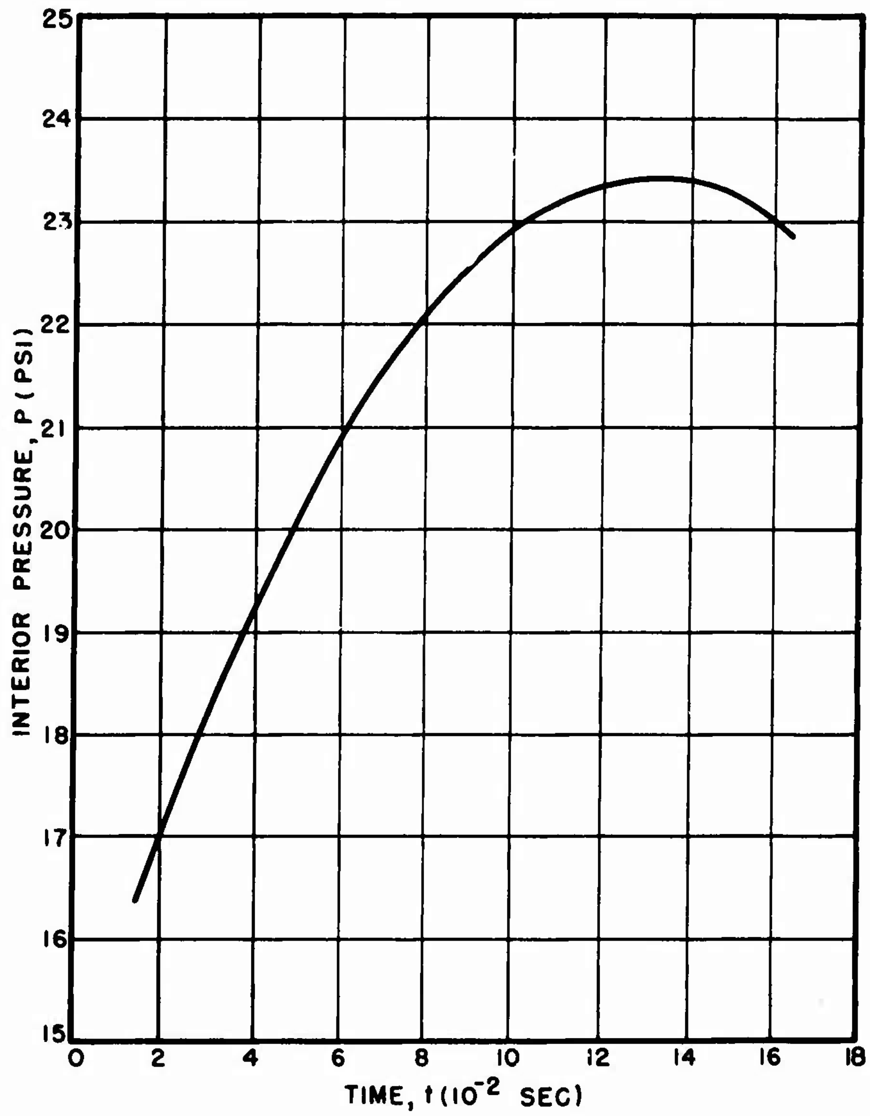


Fig. 3.10 Expected Interior Pressure vs Time in a Buttoned-up M-26 Tank at 500 Yd from Ground Zero

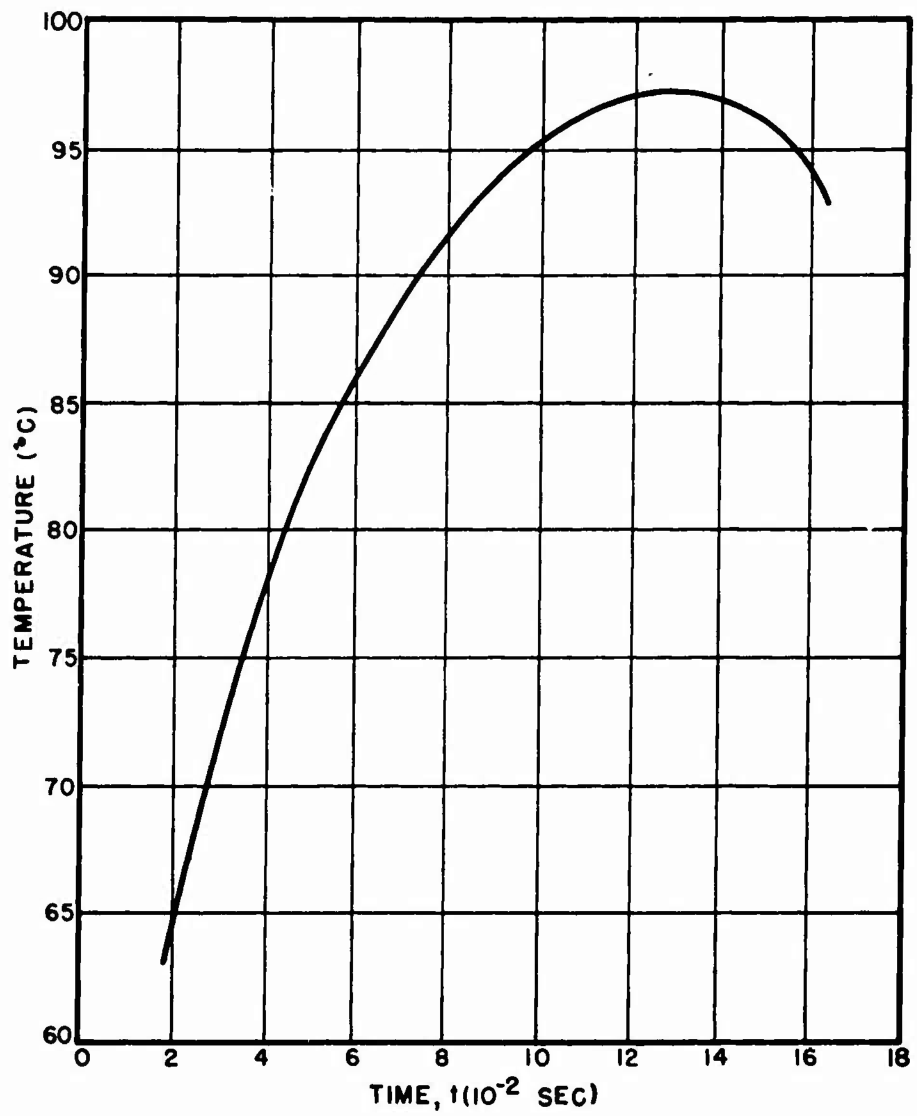


Fig. 3.11 Expected Interior Temperature vs Time in a Buttoned-up M-26 Tank at 500 Yd from Ground Zero

Chapter 4

Instrumentation

4.1 BASIC CONCEPTS FOR INSTRUMENTATION PLAN

4.1.1 Duplication

A survey of the various types of instrumentation available for measuring the effects of interest showed immediately that there were none which would be considered as having close to 100 per cent probability of operation. For example, one of the most fruitful possibilities was the use, with appropriate modifications, of instrument techniques developed for use with guided missiles. Even these known techniques were none too reliable. These considerations, coupled with the relative inexpensiveness of the instrumentation compared to the cost and importance of the tests, dictated that duplication be employed whenever possible.

This necessary duplication was achieved principally by two means. First, whenever it was at all feasible, a primary means of measurement was backed up by a secondary means of less cost and accuracy. In some cases, the backup instrumentation had a higher reliability of operation; in many others, the backup did not attempt to measure the time function of the effect, but only the maximum value. Second, the display and instrumentation of vehicles were planned with some duplication. In other words, an attempt was made to secure more than one confirming measurement of each effect.

4.1.2 Range of Measurements

Ideally, in an experiment of this kind, the expected effects are computed; then the experiment is performed, with the computations checked by measurement. Before the experiment is performed, however, the range of possible errors in the computation must be more or less arbitrarily determined, and the experiment must be designed to cover this range. In some cases this may be handled by multiple experiments, achieving the proper range by iterative means, a procedure obviously impossible in this case.

The preceding chapters have shown how the expected effects were computed. An attempt was made to be conservative in all calculations; i.e., the actual value should lie below the computed value.

As an additional safety factor, the experiment was designed to cover a possible variation of 20 per cent in the expected yield of the weapon. With these points in mind, the number and positions of the tanks to be exposed and the instruments to be placed in each were determined.

4.2 DISPLAY OF EQUIPMENT

4.2.1 Arrangement of Tanks

At a distance of 500 yd from the base of the tower, two tanks were placed, one side-on to the blast and one end-on. At 750 yd, three tanks were placed, one side-on, one with the front, and one with the tail facing the blast. This location is the one expected to represent most nearly a critical position. Two tanks were placed at 1000 yd, two were placed at 1233 yd, and one was placed at 1400 yd. Eight of these were M-26 medium tanks. Two were M-46 tanks. In armor thickness and general hull design these two types are identical. The M-46 represents the later model, having an engine of larger horsepower. Externally, however, they

differ only in the external mufflers on the M-46 and the 10-in. longer length of the later model. The details of the arrangement and the instrumentation in each tank are given in Appendix A.

In each case, the tanks were completely "buttoned-up"; i.e., all hatches were closed and locked. The guns were in travel position, with the main armament, the 90-mm gun, in the reversed position. The tanks with the side-on orientation had the barrel locked in place in the traveling yoke. All other guns were not locked and were at 0° elevation. Figure 4.1 shows a typical tank before exposure.

4.2.2 Instrumentation Arrangement

Appendix A contains the details of the exact instrumentation in each tank. It is sufficient to say that in each case the complexity, accuracy, ruggedness, and ranges of the instruments at the various locations varied in accordance with the expected results at that location. For example, Webster-Chicago recorders (see Sec. 4.3) were not used closer than 750 yd from the base of the tower, since they were not designed to withstand the expected accelerations at closer distances. Again, no effort was made to measure all components of acceleration at the more distant locations, because it was not expected that more than two or three components would be significant.

4.3 RECORDING AND CONTROL METHODS

4.3.1 General Remarks

Many of the instruments were self-recording, particularly those types which recorded only peak values. The details of all instruments are found in Appendix A. In this section are discussed the instruments which recorded more than one type of effect. They were used to measure several of the effects as functions of time.

4.3.2 Webster-Chicago Recorders

The Webster-Chicago recorder is a 24-channel phase-modulated magnetic tape recording system. It has a running time of about 5 min, a frequency response from 0 to 500 cps, and operates from a battery power source of 24 v. Similar recorders were used by Programs 3 and 8.

These recorders were used in tanks at 750, 1000, and 1233 yd to record temperatures, accelerations, and pressures. The pickups are described briefly in the following paragraphs and in detail in Appendix A.

4.3.3 Sanborn Recorders

The Sanborn recorder is a single-channel direct-writing instrument, utilizing heat-sensitive paper. It has usable frequency response to about 30 cps and a recording time of 48 hr or more. It was used to record slowly varying quantities, such as atmospheric temperature and the battery voltage supplying the Webster-Chicago recorders.

4.3.4 Control Units

The Webster-Chicago recorders were operated through specially built control units which, in conjunction with timing signals provided by landlines, turned on filament, plate, and gauge supplies at H−30 min for warm-up, recorded for a 2-min period starting at H−5 sec, and shut off equipment; they then recorded for a 5-sec period on each hour after zero, again providing the half-hour warm-up prior to each recording period.

The Sanborn recorders were operated by units which inserted calibration signals periodically, and also periodically switched from one pickup to another so that more than one signal could be recorded on a single channel.

4.4 IONIZING RADIATION

Attempts were made to measure both gamma and neutron intensity inside the tanks at all locations. Neutron measurements utilized sulfur buttons and gold foil. These were supplied, calibrated, and read by personnel of Los Alamos Scientific Laboratory (LASL).

4.4.1 Film Badges

The attempts to measure gamma intensity were considerably more complex. As might be expected, film badges of appropriate ranges were used at all locations. They were furnished, processed, calibrated, and read by personnel of the National Bureau of Standards. With the exception of those used at 500 yd, all the badges were sensitive to high temperatures, and, in

general, these effects could not be calibrated satisfactorily. Although the thermal effects of the bomb itself were not expected to affect appreciably the badges, it was expected that the effects of a day inside a closed container under a tropical sun would far exceed the temperature tolerance of the badges. In general, temperatures in excess of 50°C will cause trouble, and temperatures of about 55°C were expected from the sun.

Various expedients for overcoming this difficulty were considered. The tanks are equipped with a ventilating system, but, unfortunately, these ventilators require more power than all the instruments in even the most highly instrumented tank. The only way to supply sufficient power would be to operate the generators and auxiliary engines in the tanks. This would require full gasoline tanks and the operation of the generators and blowers from the time the shot island was vacated until recovery was effected. Tests showed that the equipment would operate satisfactorily for at least 72 hr; however, it was felt that the danger of partially full fuel tanks was too great to risk. They might rupture, and a resulting fire could destroy all records. Operation of the ventilators throughout the test was thus ruled out. However, provisions were available for fueling the auxiliary engine and starting the ventilators after the test, even though it was felt that the badges could be recovered as rapidly as the ventilators could be serviced and started.

Another possibility was that of thermal shielding for the badges. Tests showed that a pint of water in an ordinary thermos bottle would maintain a satisfactory temperature over several hours, but the effects of the water and the bottle on the badge must be considered. Rough calculations indicated that the (n,γ) reaction of the neutron flux on the water would change the gamma reading by less than 1 per cent, which would of course be indetectable. The problem of shock mounting the thermos bottles, however, was in itself a formidable one. Furthermore, the space required by an array of badges individually mounted in thermos bottles was overwhelming.

After consultation with personnel of Task Unit 3.1.5 concerning the radiological safety problems involved, it was decided to attempt to recover all badges from 750 yd out at approximately H + 5 hr, before the effects of the sun were felt upon the badges. In addition, temperature in the tanks would be recorded for possible calibration purposes, and a sample of badges in the outer tanks would be thermally shielded for control purposes.

4.4.2 Dosimeters

In addition to the film badges, other dosimetry methods were utilized. The Naval Research Laboratory furnished and calibrated phosphor glass dosimeters.

Project 2.4 (Naval Medical Research Institute) furnished phantoms simulating men. Two of these were placed in each of four side-exposed tanks, at 750, 1000, 1233, and 1400 yd; and one was placed in each of the tail-exposed tanks, at 1250 and 750 yd.

Project 5.1 furnished 60 Polaroid dosimeters (Radiac Detector DT-65). In addition, experimental dosimeters were placed in tanks at various locations in accordance with the desires of Project 5.1.

4.4.3 Residual Radiation

To determine residual radiation after the initial burst, telemetering units furnished by Project 5.2 (Bureau of Aeronautics) and a radiation monitor whose output was recorded on a Webster-Chicago recorder were used. These latter measurements gave an estimate of contamination and induced radioactivity. Similar estimates were obtained by the radiological-safety monitoring personnel.

4.5 ACCELERATIONS

4.5.1 Wiancko Accelerometers

Accelerations were measured by differential inductor accelerometers purchased from Wiancko Engineering Company. These accelerometers were used in a bridge circuit whose output was recorded on the Webster-Chicago recorders at 750, 1000, and 1233 yd.

4.5.2 Engineering Research Associates Accelerometers

In addition, self-recording accelerometers furnished by Engineering Research Associates

were used at the first three locations (500, 750, and 1000 yd), as prime instruments at 500 yd, and as backup at the other locations.

4.6 PRESSURES

4.6.1 Wiancko Gauges

The pressure changes inside the tank due to the passage of the blast wave were measured by differential inductor type gauges utilizing a twisted Bourdon tube, manufactured by Wiancko. These gauges were recorded on the Webster-Chicago recorders at 750, 1000, and 1233 yd.

4.6.2 Rupture Diaphragm Gauges

As backup, peak pressures inside the tanks were measured by rupture diaphragm type gauges similar to those used in Operation Sandstone (see Sandstone Report, Annex 5, Vol. 21, pp 4-14), except with individual cavities for each hole, in an "organ pipe" arrangement.

4.7 TEMPERATURES

4.7.1 Adiabatic Heating

Air-temperature gauges with a high response time were constructed by suspending temperature-sensitive resistance elements on nylon thread. These gauges were mounted in baffled containers to eliminate strong air currents and were used in a bridge circuit with both Webster-Chicago and Sanborn recorders. These gauges also measured the interior air temperature periodically, as the Webster-Chicago recorders were operated hourly.

4.7.2 Wall Temperature

The interior-wall temperature was measured by temperature-sensitive resistance bridges cemented to the walls. The output of these gauges was recorded on both the Webster-Chicago and the Sanborn recorders. In addition, temperature-sensitive paints were used on the exterior and interior to determine maximum temperatures reached.

Fig. 4.1 M-26 Tank Prior to Side-on Exposure at 750 Yd

Chapter 5

Results of Test Exposure

5.1 PHENOMENA AFFECTING PERSONNEL

5.1.1 Nuclear Radiation

The actual yield of the E-shot weapons was close to the predicted yield; so a comparison between predicted and actual interior gamma dosages and neutron fluxes is possible. The types of instrumentation used in obtaining the results were given in Chap. 4, and the sources of information will not, in general, be given in the present chapter.

In order to interpret the quantitative int dosage (gamma) data, it is helpful to visualize the armor-plate shielding which influenced the instrument readings. In Fig. 5.1 is shown the plan view of the M-46 fighting compartment with indicated dosimeter locations and effective shielding thicknesses. The dosage data around each crew-member position were averaged to obtain a representative value. In Figs. 5.2 to 5.6 are shown the averaged curves of integrated gamma dosage vs distance for each crew-member position for the three different tank orientations. Also included, for reference, are the predicted exterior and interior dosages. It is at once noted that the data for the side-on and tail-on vehicles at 750 yd do not fit well with the other results. The explanation for this lies in the fact that these two vehicles rolled over during the period when the delivery rate of the gamma radiation was still quite high. The time variation of the shielding thickness explains, qualitatively at least, the observed discrepancies

The rate of delivery of gamma radiation is given in Fig. 5.7 as a function of time for the side-on vehicle at 750 yd. The data shown were obtained from ionization chambers and represent both telemetered and recorded data. The humps in the rate-of-delivery curve in the vicinity of 0.6 sec and 4.5 min are not at the moment explainable. It would be necessary to examine thoroughly the exterior rate of delivery before an explanation could be attempted. Unfortunately, a malfunctioning of equipment occurred at the 1000-yd position, and no other rate-of-delivery data were obtained.

Gold and sulfur neutron flux indicators were exposed at two separate locations within one vehicle at ranges of 750 and 1000 yd. The results from the two locations were averaged to give the slow- and fast-neutron fluxes at the indicated ranges. These data are plotted in Fig. 5.8. For the purposes of comparison, available data on external fluxes are also indicated.

5.1.2 Accelerations

The acceleration data, as indicated by the applicable instrumentation, are not, by themselves, criteria for damage to crew members within the medium tank. What is important is the combination of the velocity and displacement as a function of time. For the purpose of estimating crew damage arising from rapid vehicle displacements, assumptions were made as follows:

1. The velocity of a crew member relative to the tank is the same as the tank velocity relative to the ground.
2. An impact velocity (crew relative to tank) of 7 ft/sec will result in 50 per cent immediate crew disability.
3. An impact velocity of 14 ft/sec will result in 100 per cent immediate crew disability.
4. In conditions 1 and 2 above, a displacement of 1 ft or more must occur within a period of 0.5 sec after beginning of motion.

These itemized assumptions hold only for the conditions of no forewarning and no safety-belt provisions within the vehicle. They may appear quite arbitrary, but certain justifications do exist. In an article published in War Medicine concerning human survival in falls from considerable heights, the author concludes that "The human body can tolerate and expend an acceleration of 200 g's for brief intervals during which the force acts in transverse relation to the long axis of the body."[1] In another published paper relating to the mechanism of head injury, experimental studies[2] show that profound damage to the head occurs when absorption of approximately 200 in.-lb of energy takes place in an interval of 5 msec. In still another article pertaining to experimental cerebral concussion, the authors state that the instant acceleration from 0 to 23 ft/sec produces injury (in cats), possibly resulting in death.[3]

It is possible to make very rough computations for the relative velocity between vehicle and occupant required to produce damage similar to that obtained in the experimental studies just mentioned. It is necessary to assume (a) that the weight of a man's head is 8 lb, and (b) that the acceleration of the human body is uniform when struck by the vehicle wall, with the body being uniformly depressed to a depth of 0.05 ft at the end of the acceleration. Two equations are necessary for the computations:

$$E = \frac{1}{2} MV^2 \tag{5.1}$$

$$a = \frac{V^2}{2S} \tag{5.2}$$

where E = energy acquired by head upon contact with vehicle wall
M = mass of human head
V = velocity of vehicle relative to occupant
a = average acceleration of body upon striking vehicle wall
S = average depth of body depression at end of acceleration

From Eqs. 5.1 and 5.2 and the preceding assumptions a and b, Tables 5.1 and 5.2 have been computed. They indicate the energy absorbed by the head and the acceleration of the body, as a function of vehicular velocity.

TABLE 5.1 ENERGY ABSORBED BY HUMAN HEAD AS A FUNCTION OF RELATIVE VELOCITY BETWEEN HEAD AND VEHICLE IN MOTION

Velocity (ft/sec)	Energy Absorbed (in.-lb)
5	37.4
10	150
12	216
14	294
16	384
18	486
20	600

TABLE 5.2 ACCELERATION OF HUMAN BODY WHEN STRUCK BY VEHICLE IN MOTION

Velocity (ft/sec)	Acceleration of Body (32 ft/sec^2)
10	31.2
20	125
25	195
30	280
40	500

It may be seen from the tables that relative velocities of 12 and 25 ft/sec are critical for the head and body, respectively. Although a crash helmet would increase the critical velocity for the head by a considerable amount, the presence of corners and objects within a tank would tend to reduce the critical velocity for the rest of the body. Thus the critical velocities assumed earlier appear reasonable on the basis of the rough computations just presented.

In order to determine the displacement-time records for the various vehicles, it is necessary to perform a double integration on the acceleration-time data. For a vehicle in which free rotation as well as free translation is possible, six accelerometers are necessary to define completely the motion, and the differential equations are rather tedious to solve. Unfortunately, for those vehicles in which six accelerometers were installed, data were obtained for 5° of freedom at the most. It was impossible, then,

to solve for displacement-time curves. However, it was possible to integrate acceleration-time data to obtain velocity-time records up to that time when rolling motion took place. In Appendix B, the complete acceleration-time records are presented, as well as the significant integrated velocity-time curves. Figures 5.9 and 5.10 show the maximum velocity vs radial distance from the tower for the head- and side-on orientations, respectively. With the exception of the vehicles at 750 yd, the maximum velocities occurred within 0.5 sec of blast wave arrival; so it is possible to indicate the distances from ground zero at which 50 and 100 per cent combat-crew casualties would have occurred. It should be pointed out that the data at 750 yd are not truly representative of the conditions hitherto assumed for the weapon used in this exposure. The shock (or compression) wave arrived at this range (in the vicinity of the vehicles at least) considerably before the predicted time and hence was much stronger than predicted (see Appendix B).

5.1.3 Thermal Radiation

There were no reliable indications of a temperature rise occurring on the interior wall of the fighting compartment at any distance from ground zero.

5.1.4 Blast Pressures and Temperatures

Peak interior tank overpressure records were obtained at 500, 750, 1000, and 1233 yd from ground zero. Interior pressure-time and temperature-time data were obtained at 750, 1000, and 1233 yd. The interior pressure-time and temperature-time curves at 750 yd are interesting because of the double peaks occurring in both. These data are given in detail in Appendix B. In Figs. 5.11 and 5.12 are shown the interior peak overpressures and peak temperature rises, respectively, as functions of distance. For purposes of comparison, the predicted peak exterior overpressure is also indicated. It is quite apparent that the natural openings into the tank are of such sizes as to reduce interior peak pressures greatly, when compared to exterior values, for small positive-phase durations but to reflect closely the ambient conditions when distances of 1233 yd are reached. In any case, the ill effects on crew personnel from interior pressure or temperature rises are small for ranges at which the vehicle sustains only minor structural damage.

5.2 EFFECTS ON MATERIEL

The emphasis in this portion of the test was a determination of the over-all immediate combat effectiveness of medium tanks located at various ranges from ground zero and having different orientations relative to the burst point. A secondary field of interest was an estimate of the degree of maintenance and the number of man-hours required to return the vehicle to minimum combat effectiveness. Minimum combat effectiveness is characterized by normal mobility, normal armament, either primary or auxiliary fire-control instruments, and some means of communication, either by radio or flag. The degree or category of maintenance required falls into the three basic groups already defined in Sec. 2.2—depot, organizational, and field.

The results of the physical examination of the vehicles are given in full detail in Appendix C. It is sufficient here to describe briefly the general effects on the individual tanks.

The side-exposed M-46 tank, range 500 yd from ground zero, rotated 180° in yaw and was displaced radially approximately 60 ft away from the burst point. Sometime during the rotation, the turret left the tank and came to rest approximately 120 ft from the initial vehicle location. That this separation occurred early in the rotation may be inferred from the high peak overpressure recorded in this vehicle. The engine was started from external batteries after the water was removed from the fuel tanks, but it did not fire on all cylinders. The remaining damage suffered was of a minor nature, but the vehicle was 0 per cent combat effective from the loss of the turret.

The head-exposed M-26 tank, range 500 yd from ground zero, suffered relatively minor damage and was estimated to be 75 per cent combat effective. It was displaced radially approximately 20 ft and rotated approximately 25°. Engine performance and mobility were satisfactory.

The side-exposed M-26 tank, range 750 yd from ground zero, rolled 180° and was displaced radially approximately 50 ft. With the help of two other tanks this vehicle was righted

and found to operate satisfactorily, and the damage sustained was minor. There was considerable acid corrosion within the fighting compartment from the overturned batteries used for instrumentation purposes, which would normally not be encountered. One road wheel was bent, having been struck by an NOBL blast pylon. The vehicle was estimated to be 0 per cent combat effective.

The head-exposed M-26 tank, range 750 yd from ground zero, was damaged slightly. It was displaced approximately 45 ft radially and 8 ft transversely (clockwise when viewed from above). Combat effectiveness was estimated as 75 per cent.

The tail-exposed M-26 tank, range 750 yd from ground zero, pitched through an angle of 180° and was displaced radially approximately 53 ft. Considerable interior damage was done by acid corrosion, for reasons already indicated, which would normally not be encountered. The engine was unserviceable and would not operate when the vehicle was righted. The elevating mechanism for the 90-mm gun was likewise found to be unserviceable. The time required to restore this vehicle completely was greater than for any of the other tanks exposed. The estimated combat effectiveness was 0 per cent.

The side-exposed M-26 tank, range 1000 yd from ground zero, suffered only minor damage. The displacement was only 3 ft. A missing aerial and a frozen 30-caliber bow gun were responsible for reducing the immediate combat effectiveness to an estimated 75 per cent.

The head-exposed M-26 tank, range 1000 yd from ground zero, was estimated to be 100 per cent combat effective.

The side-exposed M-26 tank, range 1233 yd from ground zero, was estimated to be 100 per cent combat effective.

The tail-exposed M-26 tank, range 1233 yd from ground zero, was estimated to be 100 per cent combat effective.

The side-exposed M-26 tank, range 1400 yd from ground zero, was estimated to be 100 per cent combat effective.

Certain general remarks apply to effects on the tanks which are functions of distance alone and not peculiar to any one vehicle. These are as follows:

1. Sandblast was sufficient to remove all trace of scorching out to a distance of 1000 yd from ground zero.
2. The 50-caliber AA gun mounted on the turret roof is lost within 1000 yd of ground zero.
3. The dust and sand deposit is appreciable at all ranges of exposure, including 1400 yd from ground zero.
4. Non-load-bearing metal structures on the tank (fenders, fender boxes, mufflers, etc.) are damaged or removed at distances less than 1233 yd from ground zero.
5. Exposed optical parts are damaged by sandblast at ranges of less than 1000 yd.

As a result of the tests at Operation Crossroads, certain modifications were made in the inspection covers between the engine and fighting compartments, and an additional hold-down hasp was placed on the hatch above the tank commander. These modifications apparently were successful, since no inspection covers or hatches were forced open on those vehicles which did not overturn.

It is important to note that the results observed at 750 yd are probably not representative. There is reason to believe that one of the observed jets struck close to this position and distorted the normal conditions by an appreciable amount.

A target bull's-eye is given in Fig. 5.13; this shows at a glance the combat effectiveness, in percentage values, of the medium tank at various distances from ground zero. Data are also included on the degree of maintenance required to return vehicles to minimum combat effectiveness, as well as other items of importance to the field commander. Figures 5.14 to 5.23 show photographs of the vehicles after exposure to the blast. In Table 5.3 are summarized the percentage of combat effectiveness of the various vehicles and the number of man-hours required to return them to minimum combat effectiveness. In interpreting this table, the following points should be noted:

1. The maintenance time and the class of maintenance will vary with every tactical situation. To eliminate as many variables as possible, no tactical situation has been assumed in the preparation of these data. All variables which are dependent on the tactical situation are additive to the data presented in this report.
2. The time required for maintenance is the minimum actual working time to correct the deficiencies resulting from the atomic blast, assuming that qualified personnel, tools, and spare parts are at hand.

TABLE 5.3 PERCENTAGE OF COMBAT EFFECTIVENESS AND REQUIRED NUMBER OF MAN-HOURS NECESSARY TO RESTORE THE TANKS TO IMMEDIATE COMBAT EFFECTIVENESS*

Range (yd)	Vehicle No.	Estimated Average Combat Effectiveness of Vehicles (%)	Estimated Average Time Required for Minimum Repairs (hr)	Category of Maintenance	Estimated Average Time Required for Complete Restoration of Vehicle (hr)	Category of Maintenance
500	063	75	2.5	Organizational	20	Organizational
	833	0	33.5	Depot	68	Depot
750	120	0	19.0	Field	74	Field
	257	75	6.5	Field	34.5	Field
	954	0	12.0	Field	36	Field
1000	440	100	0.0	Organizational	7	Organizational
	117	75	1.0	Organizational	0.7	Field
1233	424	100	0.0	Organizational	2	Organizational
	872	100	0.0	Organizational	7.5	Organizational
1400	418	100	0.0	Organizational	5	Organizational

*Combat effectiveness for immediate action: normal mobility, normal armament, either primary or auxiliary fire-control instruments, and some means of communication, either radio or flag.

3. The category of class of maintenance is based on the type of work to be done without consideration of probable maintenance loads.

REFERENCES

1. H. De Haven, Mechanical Analysis of Survival in Falls from Heights of Fifty to One Hundred and Fifty Feet, War Med., 2(4): 586-596 (July 1942).
2. E. S. Gurdjian and J. E. Webster, Experimental and Clinical Studies on the Mechanism of Head Injury, Research Pubs., Assoc. Research Nervous Mental Disease, 24: 90-91 (1945).
3. D. Denny-Brown and W. Ritchie Russell, Experimental Cerebral Concussion, J. Physiol. (London), 99: 153 (1940).

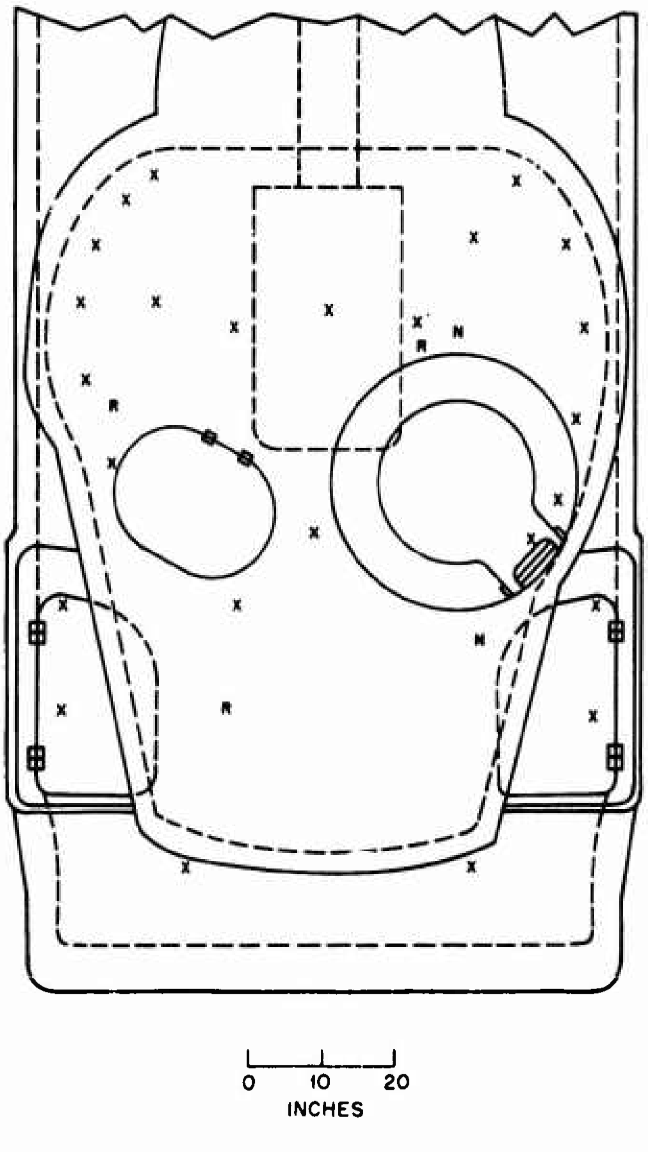


Fig. 5.1 Plan View Showing Relative Thicknesses of Armor in an M-46 Tank and Locations of Dosimeters: X, Film Badges and Polaroid Dosimeters; R, Radiophoto-luminescent Glass Dosimeters; N, Neutron Flux Indicators

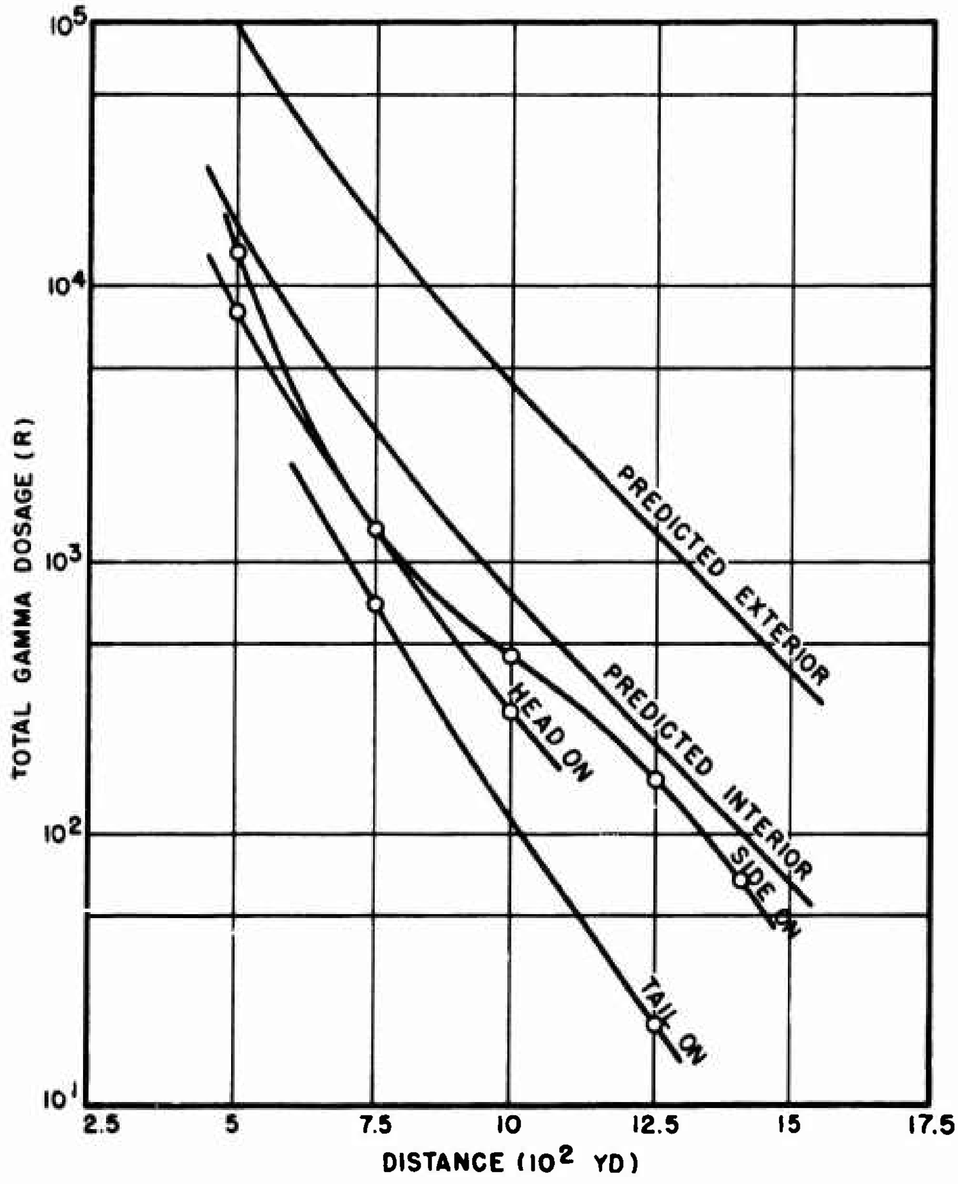


Fig. 5.2 Roentgen Dosages vs Distances at Driver's Position for Various Tank Orientations

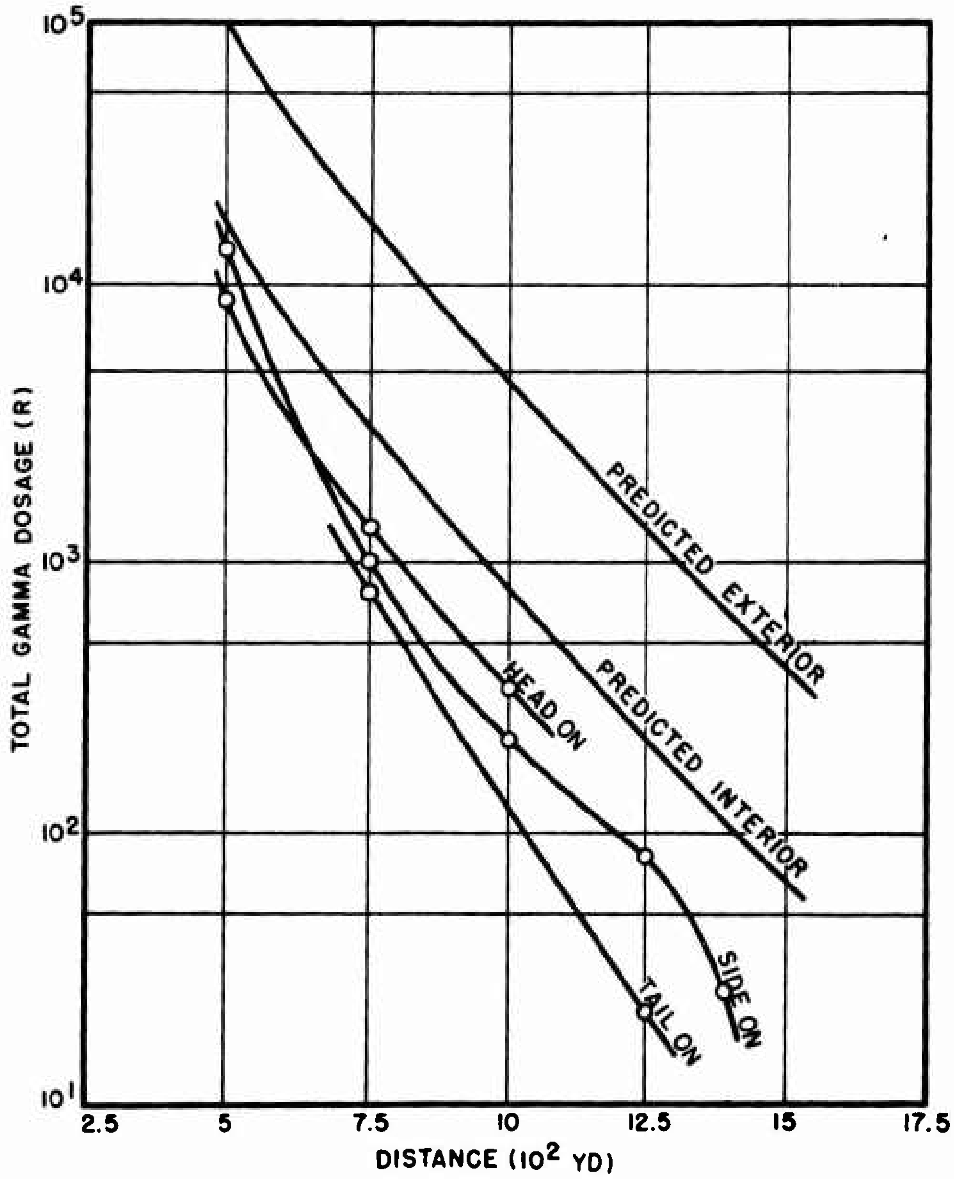


Fig. 5.3 Roentgen Dosages vs Distances at Assistant Driver's Position for Various Tank Orientations

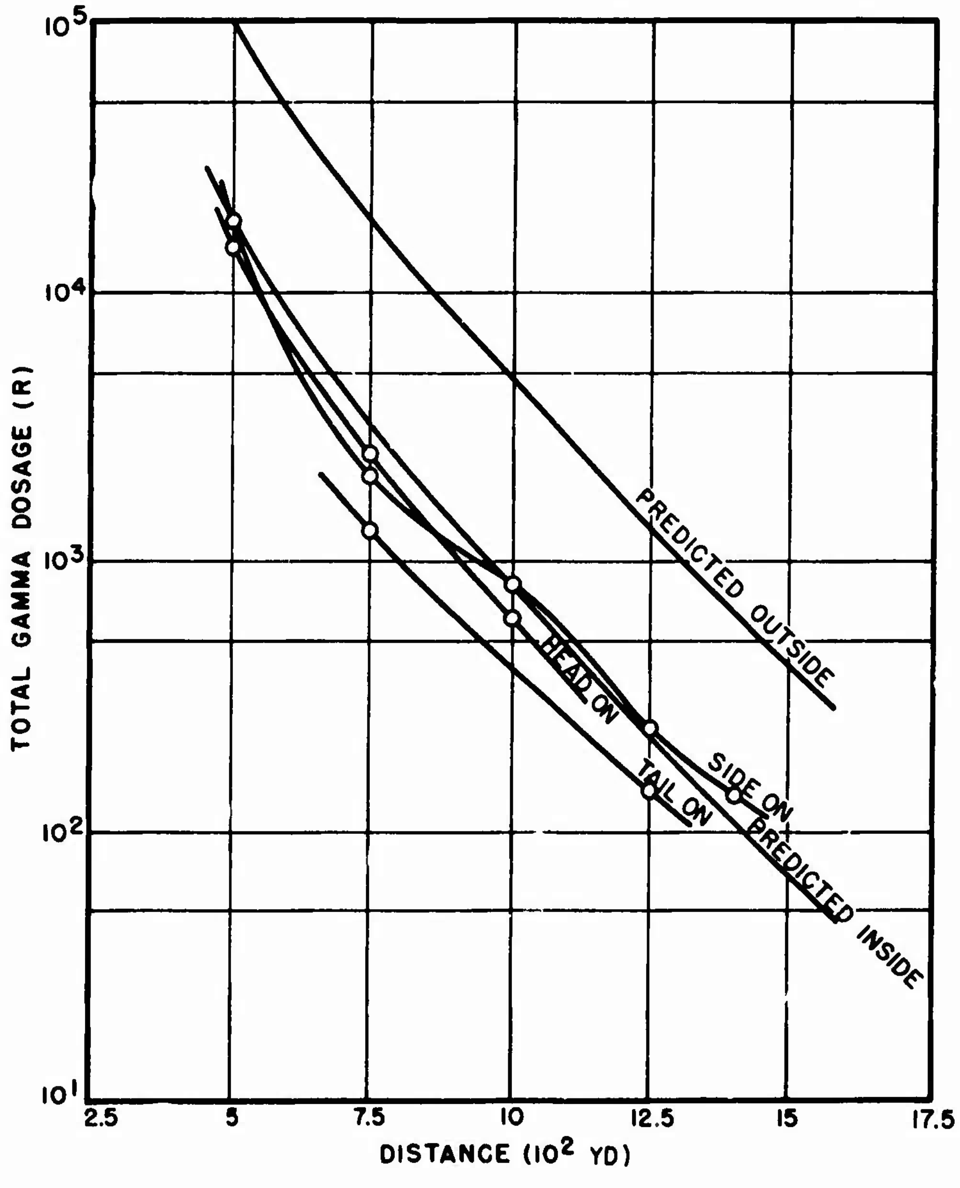


Fig. 5.4 Roentgen Dosages vs Distances at Commander's Position for Various Tank Orientations

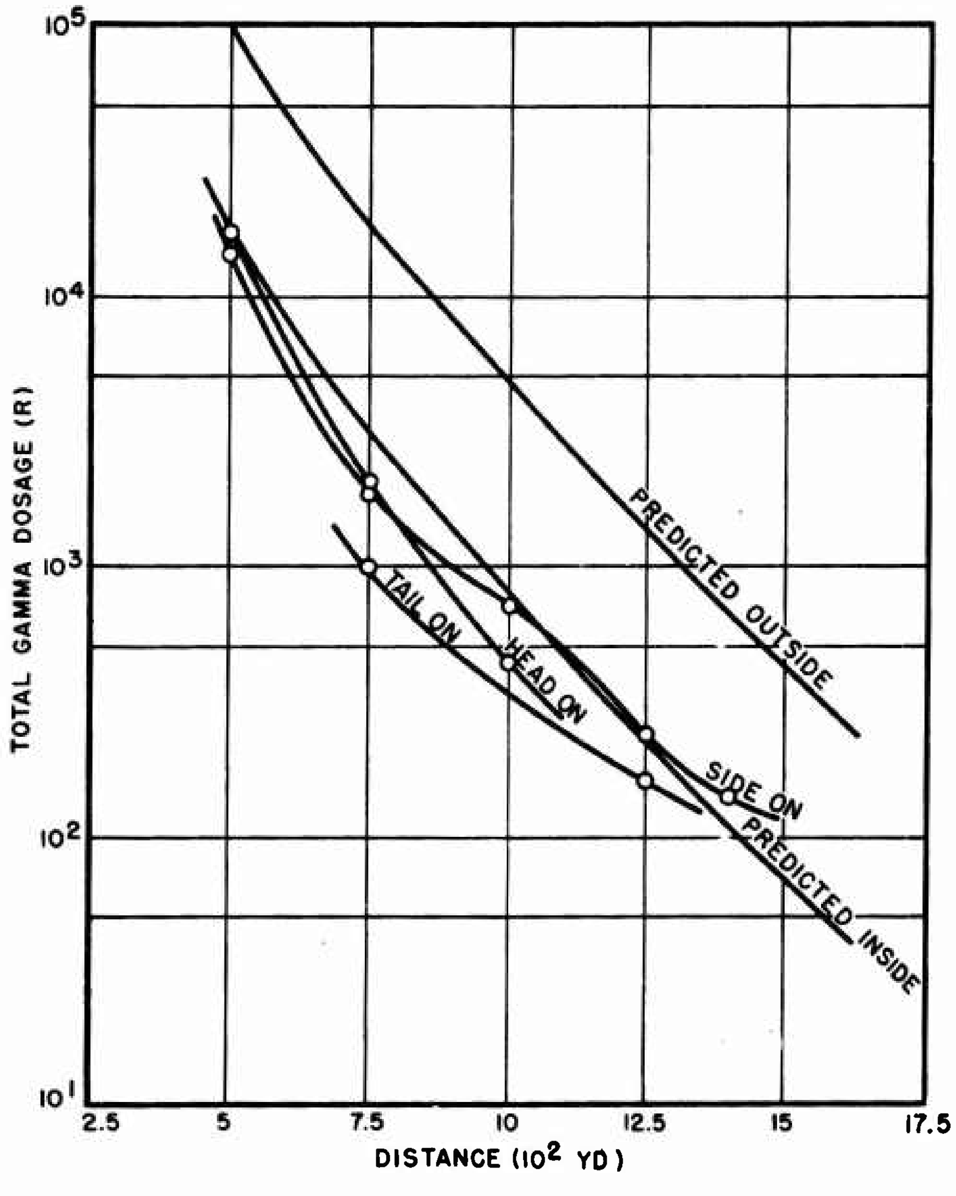


Fig. 5.5 Roentgen Dosages vs Distances at Gunner's Position for Various Tank Orientations

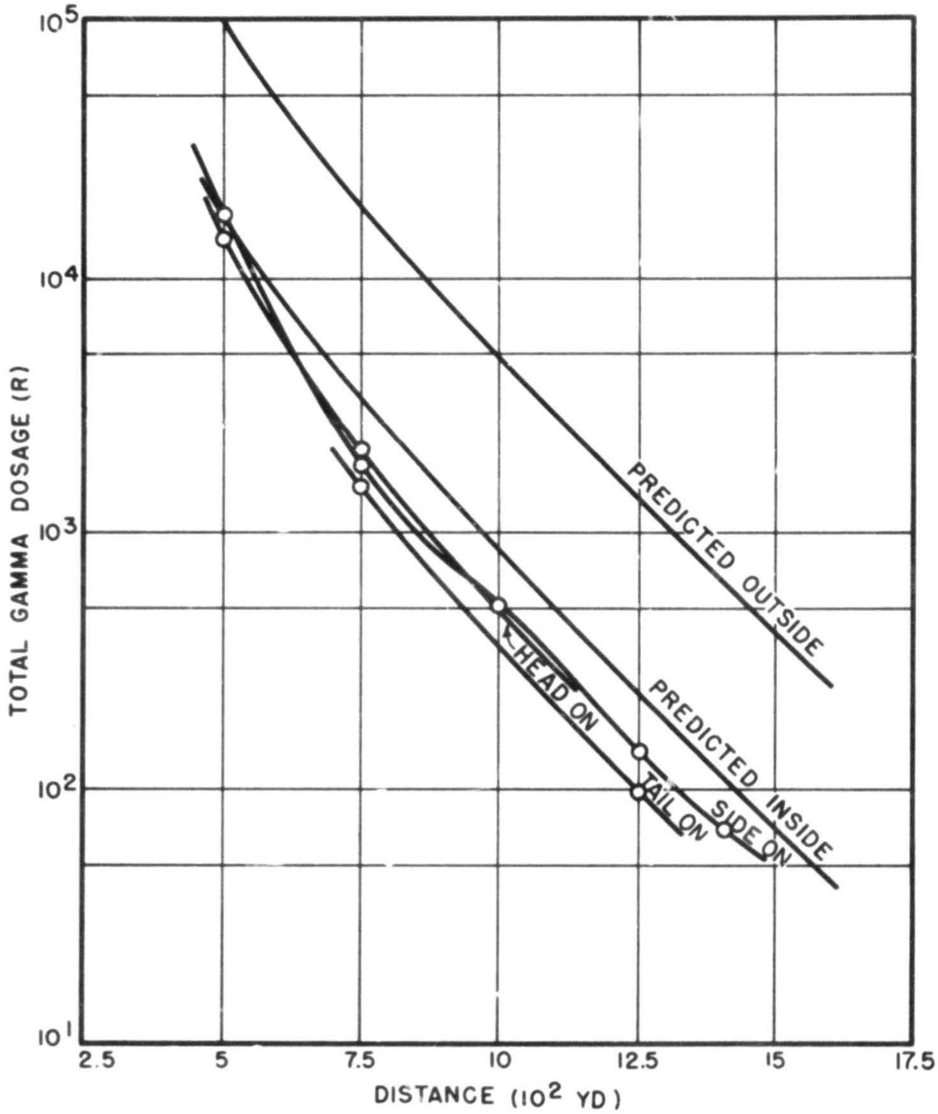


Fig. 5.6 Roentgen Dosages vs Distances at Assistant Gunner's Position for Various Tank Orientations

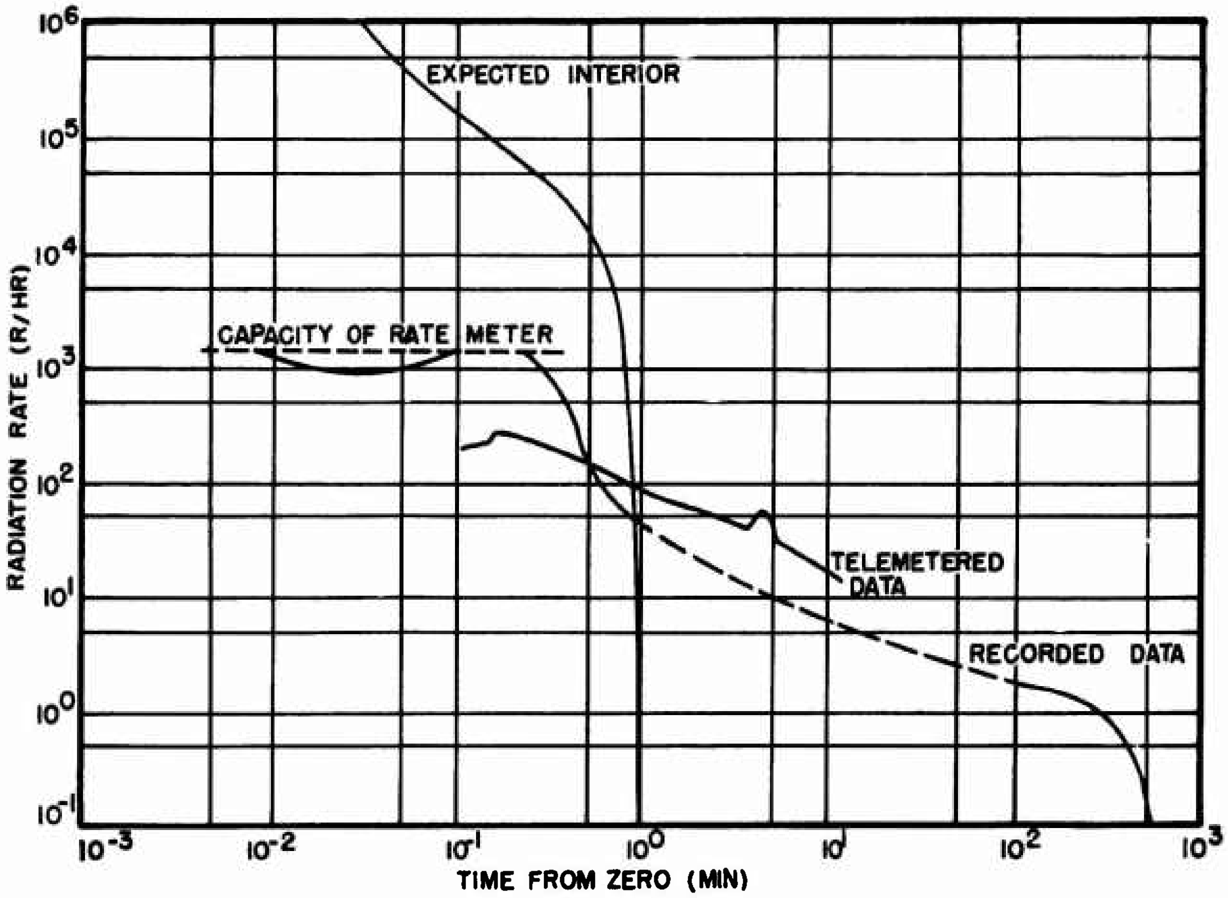


Fig. 5.7 Roentgens per Hour vs Time within the Side-exposed Tank at 750 Yd

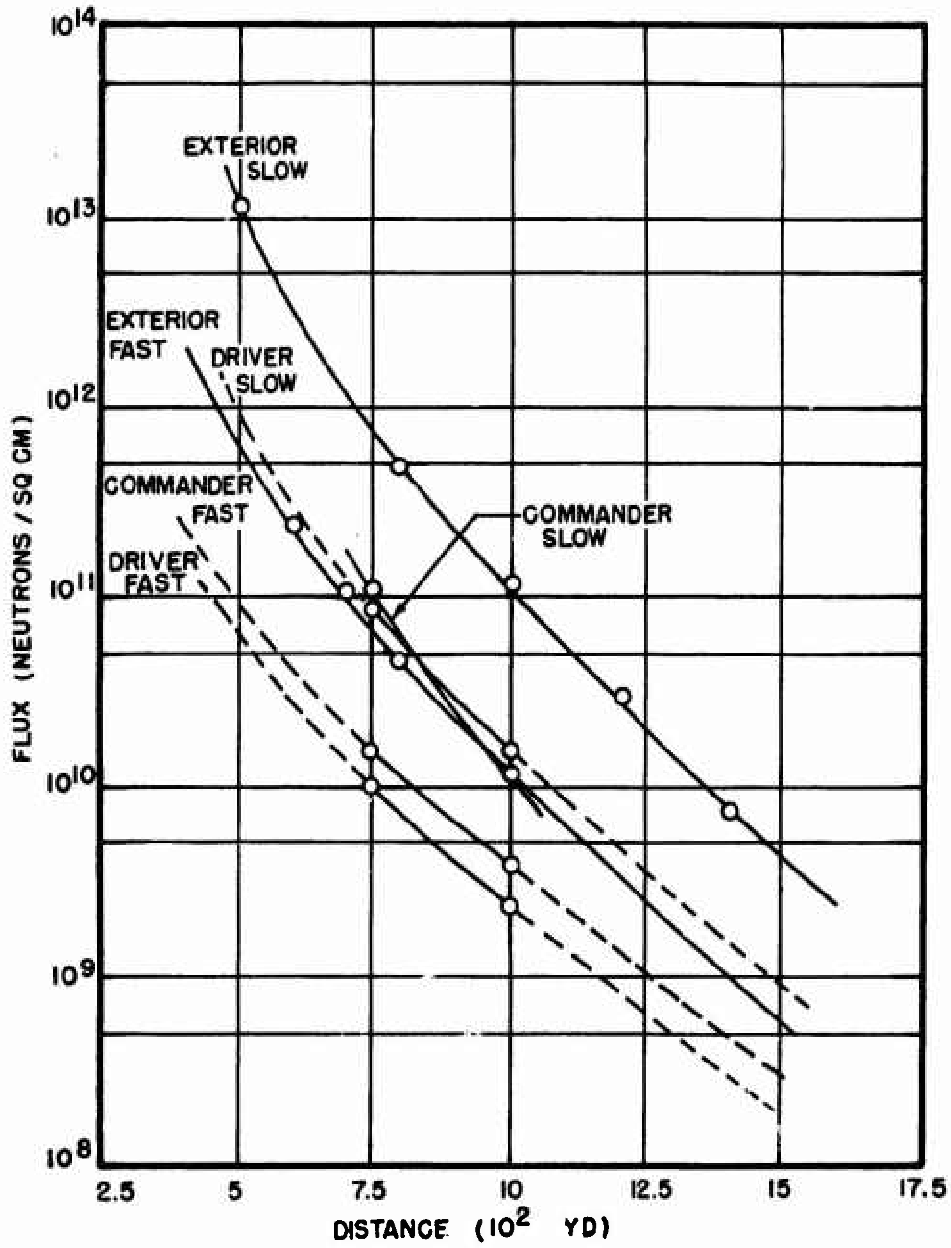


Fig. 5.8 Fast- and Slow-neutron Fluxes Exterior to the Tank and in the Driver's and Commander's Positions within the Tank

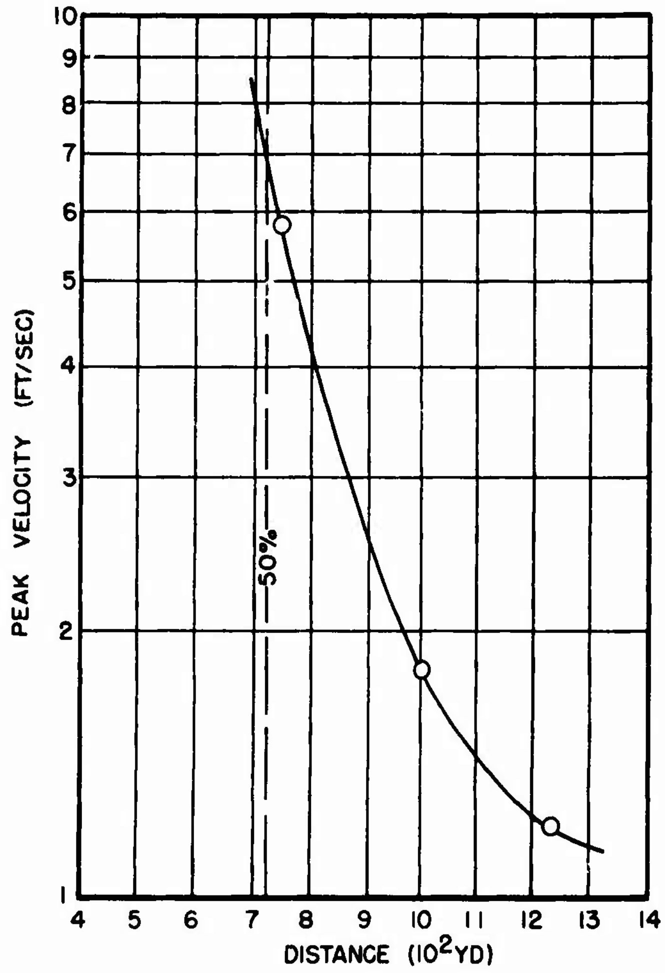


Fig. 5.9 Peak Radial Velocities for Head-on Orientations at Various Distances from Ground Zero

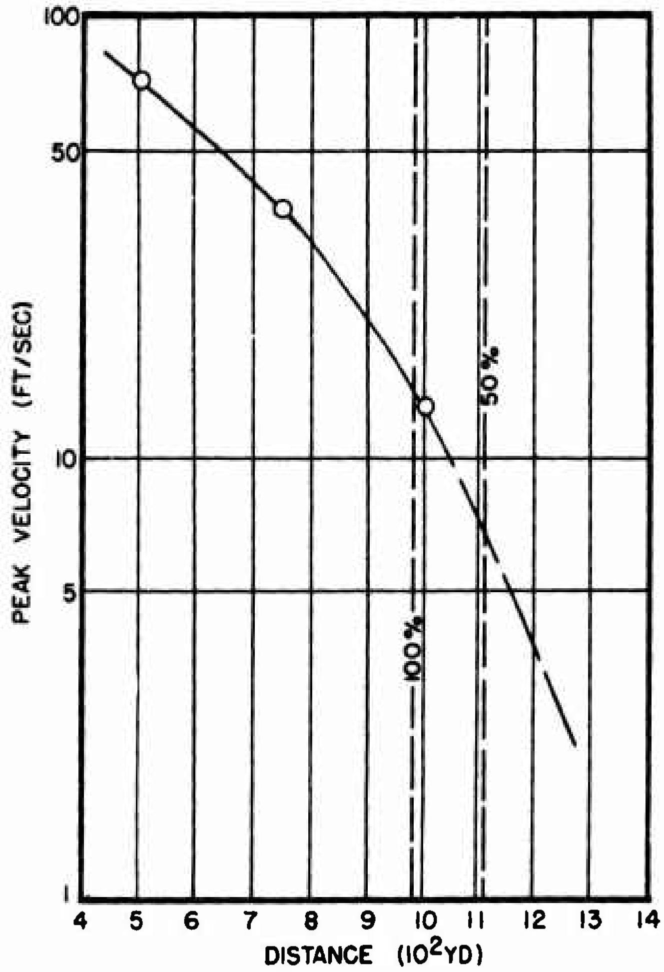


Fig. 5.10 Peak Radial Velocities for Side-on Orientations at Various Distances from Ground Zero

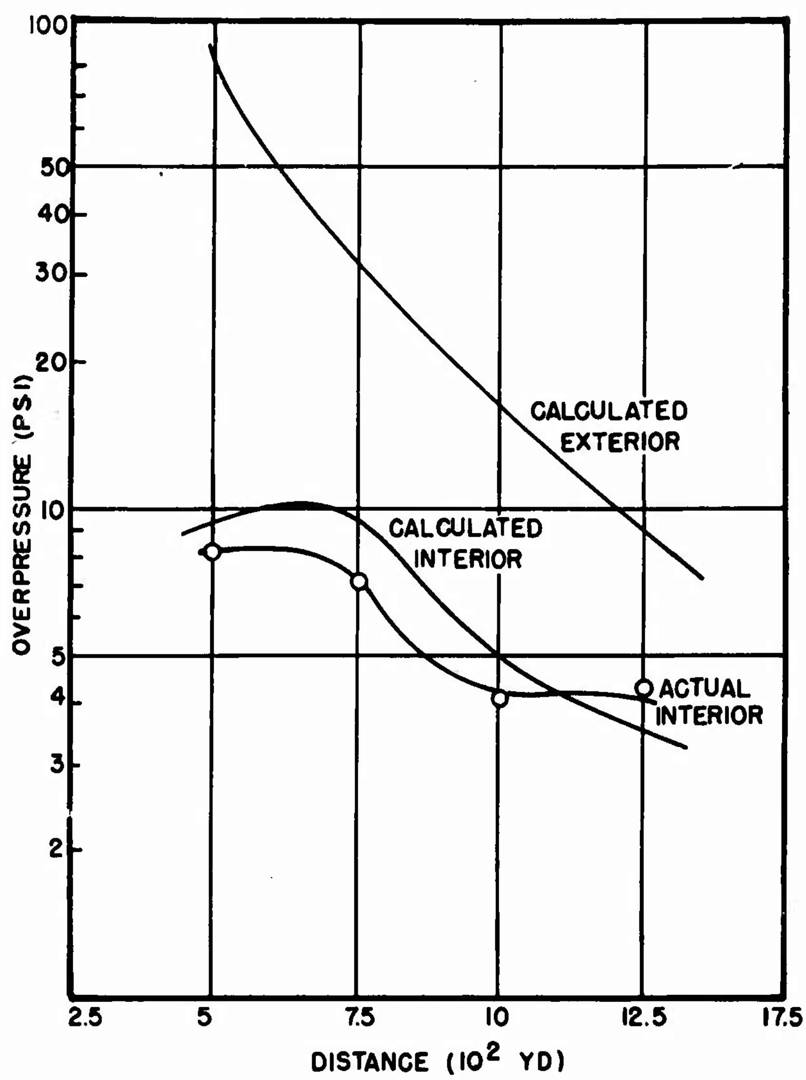


Fig. 5.11 Calculated Exterior, Interior, and Measured Interior Peak Overpressure vs Distance

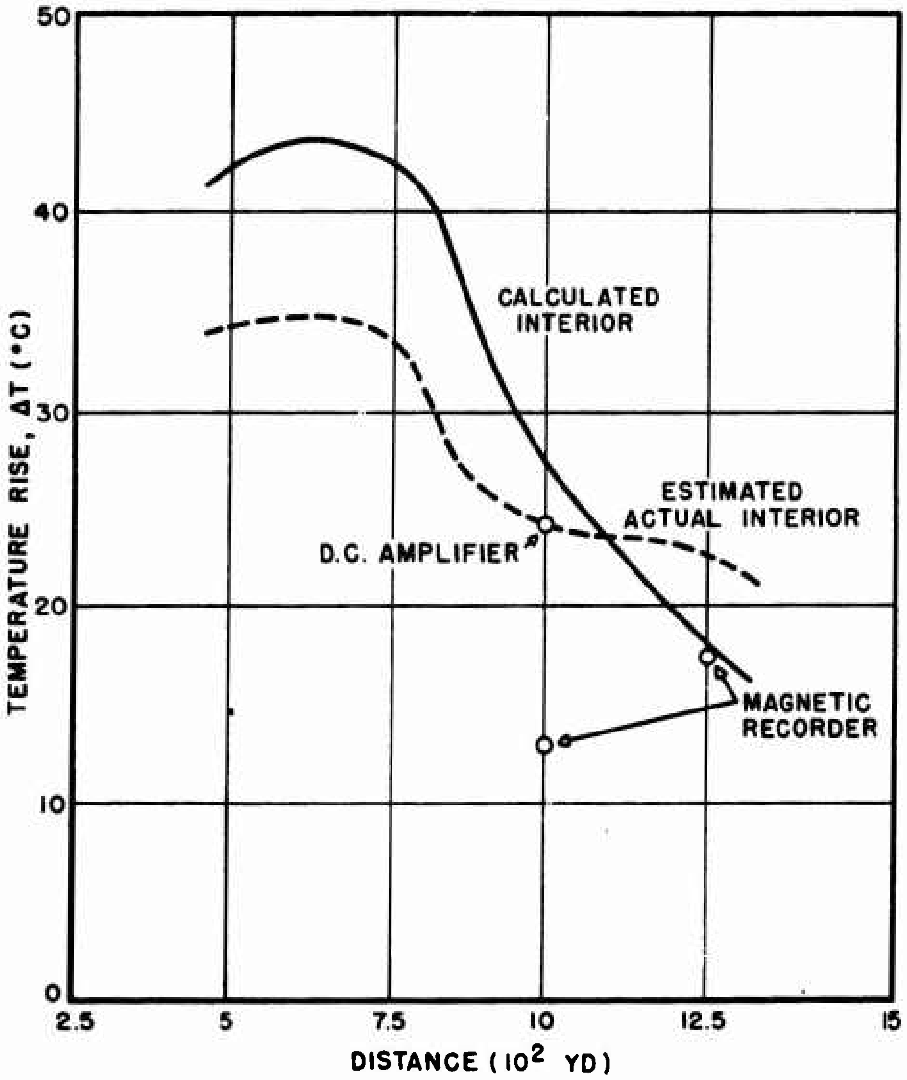


Fig. 5.12 Peak Interior Temperature Rise vs Distance

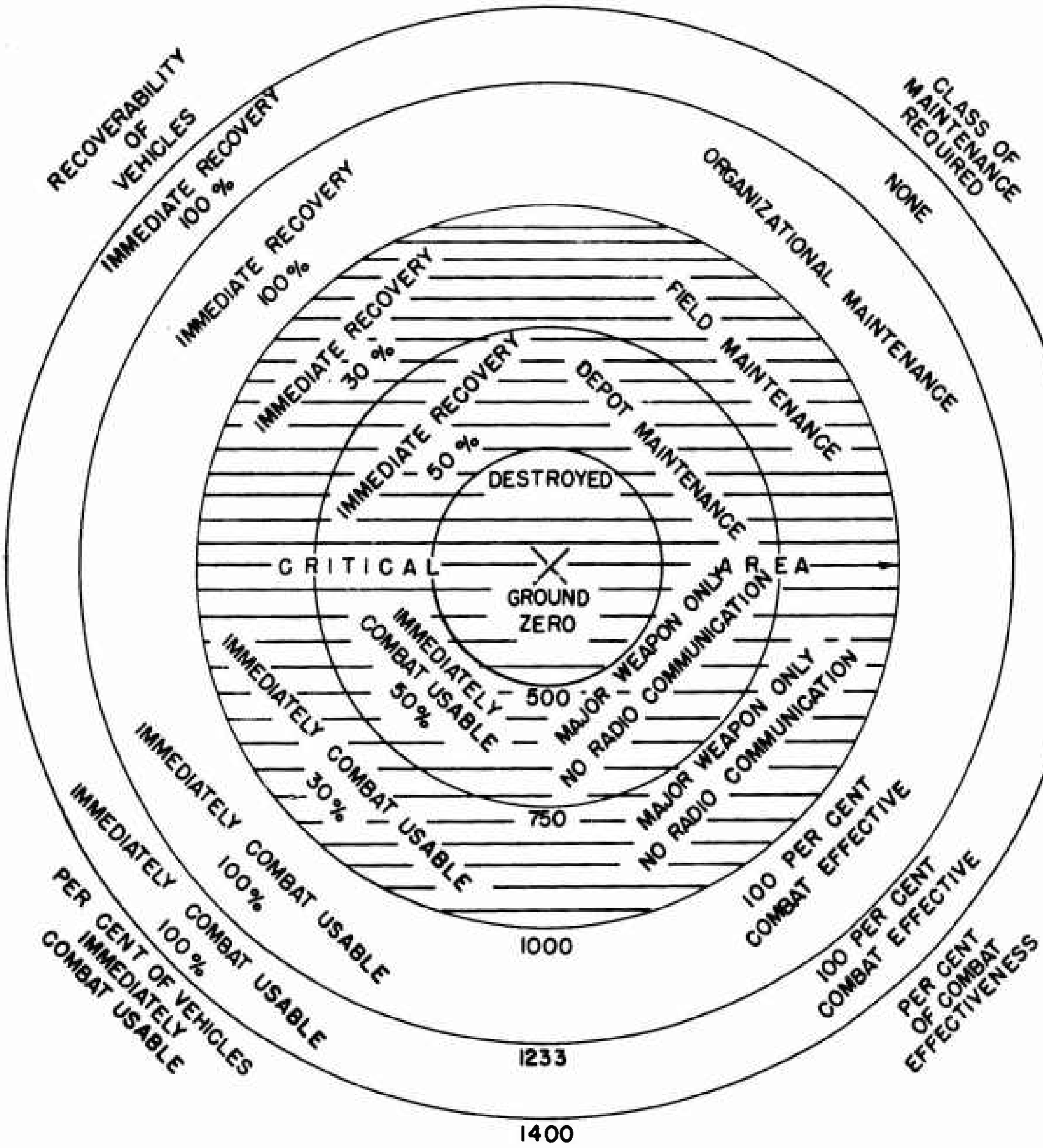


Fig. 5.13 Evaluation of Mechanical Factors Affecting the Combat Usability of Medium Tanks under Specific Conditions of Easy Shot, Operation Greenhouse

Fig. 5.14 Side-on Tank after Exposure to Blast, 500 Yd

Fig. 5.15 Head-on Tank after Exposure to Blast, 500 Yd

Fig. 5.16 Side-on Tank after Exposure to Blast, 750 Yd

Fig. 5.17 Head-on Tank after Exposure to Blast, 750 Yd

Fig. 5.18 Tail-on Tank after Exposure to Blast, 750 Yd

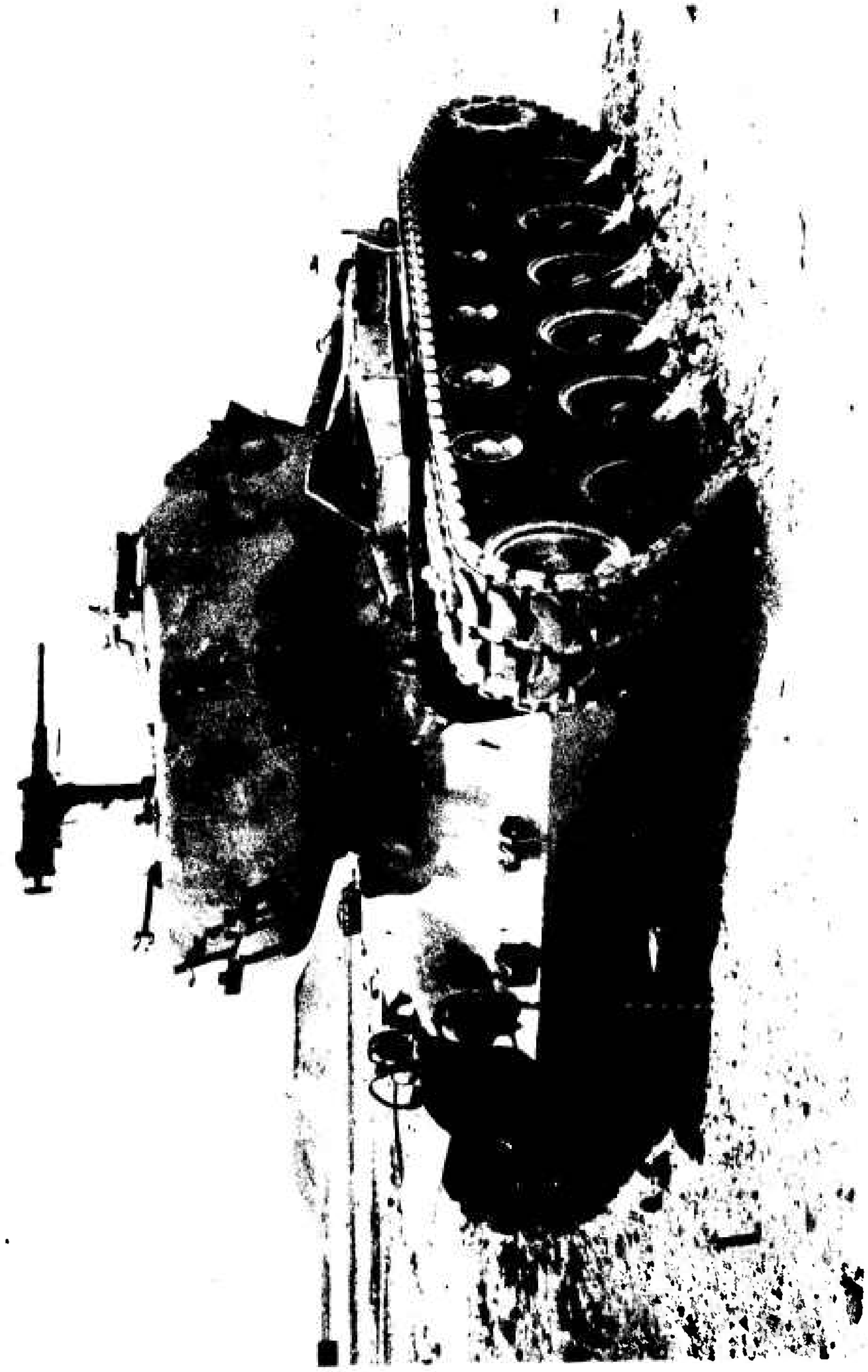


Fig. 5.19 Side-on Tank after Exposure to Blast, 1000 Yd

Fig. 5.20 Head-on Tank after Exposure to Blast, 1000 Yd

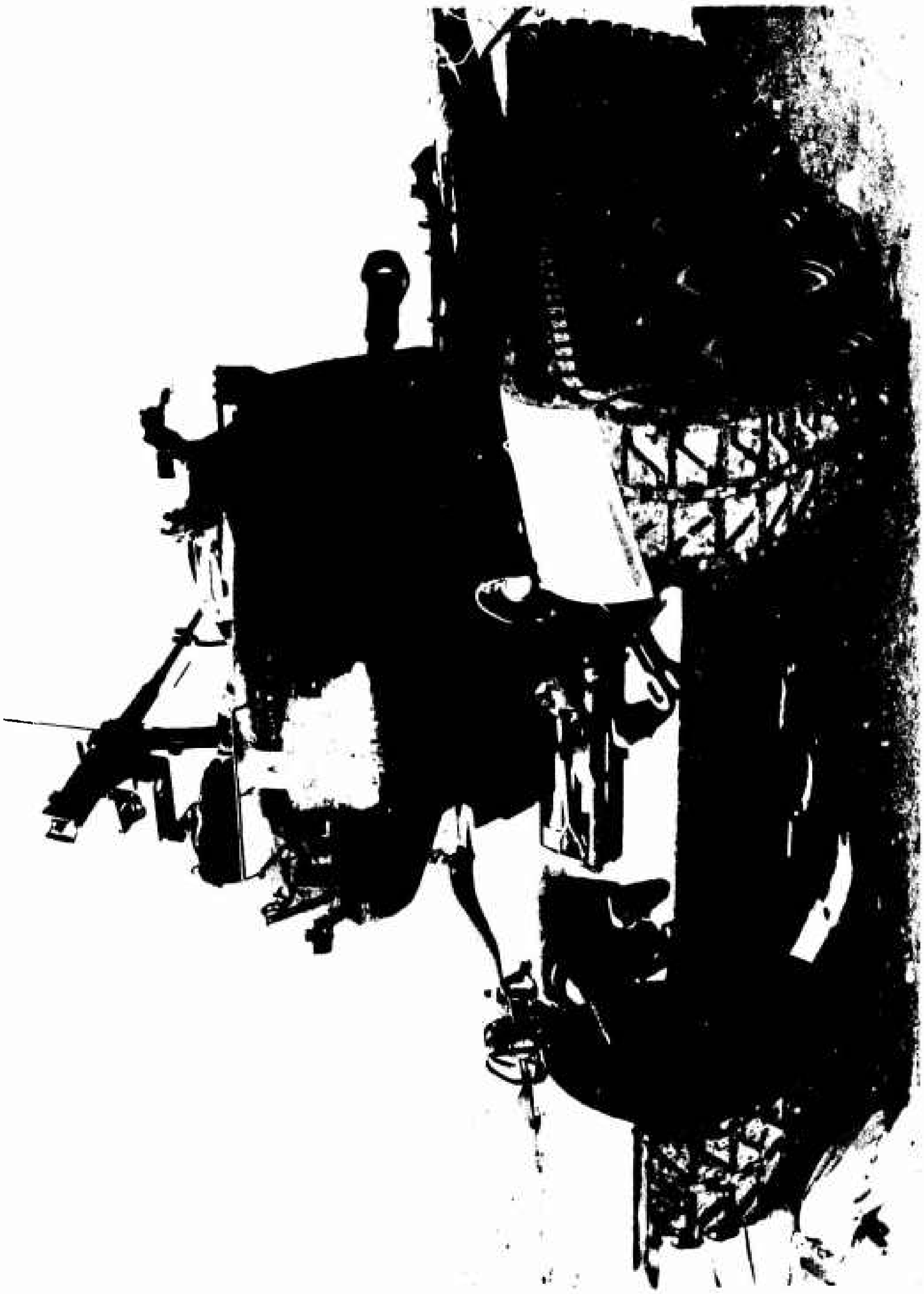


Fig. 5.21 Side-on Tank after Exposure to Blast, 1233 Yd

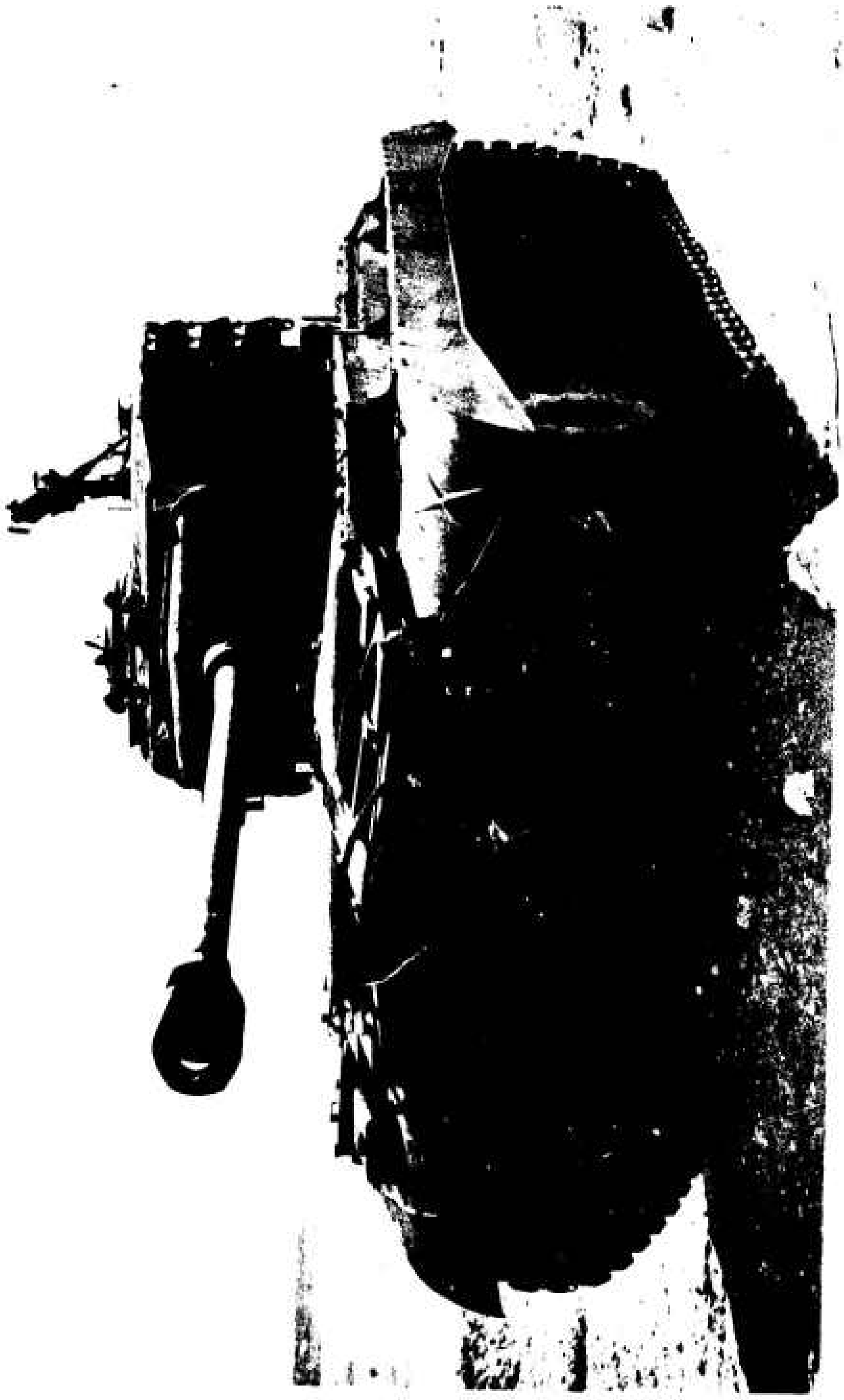


Fig. 5.22 Tail-on Tank after Exposure to Blast, 1233 Yd

Fig. 5.23 Side-on Tank after Exposure to Blast, 1400 Yd

Chapter 6

Future Experiments

6.1 LABORATORY PROGRAM

In order to decide on the instrumentation to be used in Operation Greenhouse, predictions of the magnitude of the various effects were necessary. These predictions were based on the considerations outlined in Chaps. 2 and 3. Chapter 5 and Appendix B show, where possible, the comparison between the predicted results and those actually measured. The predicted interior effects were based on predicted exterior effects. In practice, the predicted exterior conditions were not reproduced exactly, and at this writing records of the actual effects are not available. Nevertheless, when the information becomes available, corrections can be made for the difference between the predicted exterior conditions and those encountered, as well as for the errors in the predictions concerning the tanks analyzed.

It is believed that a careful stuay oi the results gained from Operation Greenhouse and from future tests, together with a study of the significant differences between tanks and other ordnance equipment, will result in a means of making adequate predictions of the effects of atomic weapons on all ordnance equipment, without the necessity of statistical testing of all items, an obvious impossibility. Such predictions might be based on comparison of similar components (the barrel of the gun on a tank is not significantly different from the barrel of a piece of artillery), or on a system of scaling laws, or some other scheme. In any case, the resulting predictions should be confirmed or disproved by spot checks at future tests.

6.2 FIELD TESTS

The continuation of the test program should fall into two categories. First, the information concerning medium tanks should be completed. Second, tests on other equipment should be made.

6.2.1 Effects on Materiel

On Easy shot, at Operation Greenhouse, jets were formed in the fireball which produced pronounced asymmetries. The tanks exposed at 750 yd were close to one of these asymmetries. There is good reason to believe that the results were appreciably affected by this fact and that they were not typical. Reference to Appendix C will show that, in general, the vehicles which moved appreciably moved not only radially from the tower but also in a clockwise direction. This is away from the jets just mentioned. It is further noted that the vehicle facing the tower at 500 yd did not move so far as that similarly oriented at 750 yd. Consideration of these facts leads to the conclusion that some verification in this range is desirable.

In order to complete the data on tanks, certain other data are necessary. The situation at Operation Greenhouse varied from that which would be expected in a combat situation in a number of ways. Among the more important differences are the following:

1. The vehicles carried no ammunition.
2. All hatches were closed and locked.
3. The brakes were set and locked.
4. The gasoline tanks were full of either gasoline or water.

5. The vehicles were either perpendicular to or aligned with the expected direction of the blast.

Based on the experience of Operation Crossroads, it is believed that the ammunition would not be affected by the direct effects of an atomic explosion.[1] However, ammunition stored in ready racks might very well be dislodged and thereby injure the crew. Blows on the primer might cause the ammunition to detonate as well. In a subsequent test, dummy ammunition should be stored in the vehicles, and the results observed. This could not be done on Greenhouse for fear of injury to the instrumentation.

The normal condition, unless under attack, is for hatches to be open or closed but not latched. The effects of this condition on both the crews and the interior of the tanks should be observed in a future test.

Brakes are not normally set in the field, unless the vehicle is parked on a slope. Computations of the effects on acceleration and velocity of having the brakes released have been made and should be checked.

At Greenhouse all gasoline tanks were filled with gasoline, except two which were filled with water. There were no fires and no broken tanks. It is believed that with fuel tanks in the more normal condition of half-full no damage would be experienced, except at distances where other and major damage would also result (i.e., considerably closer than the 500 yd at Greenhouse). At the time other tests are made, however, this point should be checked.

As this is written, computations of the effects of oblique orientation of medium tanks are under way. The results of this work should be checked, particularly if they indicate that effects would be more serious than with the parallel or perpendicular orientation. (Preliminary results indicate that this may be true.)

The possibility of extrapolation from medium tanks to other ordnance equipment was mentioned earlier in this chapter. It is emphasized that concomitant with the hope that such extrapolation can be made is the necessity for gaining as complete a knowledge as possible of the item chosen for careful experimental investigation, hence the emphasis on seemingly trivial points of information. The importance of statistically significant results was mentioned in Sec. 1.4, and further tests with the same items will help to provide statistically significant data.

It should be mentioned at this point that it is entirely feasible to use for future experiments the same vehicles that were used at Operation Greenhouse. Additional tanks are not necessary, and the principal cost of such tests would be that of transportation.

6.2.2 Effects on Personnel

The effects on personnel cannot be completely separated from those on materiel. The relatively minor subjects of stored ammunition and of hatches have already been discussed. In addition, certain other questions will bear further examination.

The contaminability of, and effective decontamination procedures for, tanks should be studied. In addition, dust samples inside the vehicles should be collected and counted. It appears very possible that long-time deleterious effects on personnel could be experienced from the dust, and the real extent of this possible hazard should be determined. Programs already under way along these lines should be utilized as much as possible.

REFERENCE

1. Final Report of Atomic Bomb Tests, Jan. 27 to Sept. 30, 1946, Vol. IV, pp 221-252.

Chapter 7

Conclusions and Recommendations

7.1 INTRODUCTION

The statements made in this chapter are limited by the lack of knowledge of exterior conditions at Easy shot, Operation Greenhouse, at the time of writing. These conclusions should be revised and made more general when additional information becomes available.

At distances at which no serious damage is done to a medium (40-ton) tank, the crew will suffer heavily. This was true under the conditions of the test, which were advantageous to the crew, and the difference would be even more striking under more normal conditions. No consideration has been given to possible psychological effects; it appears to the authors that very careful conditioning would be necessary to prevent loss of crews at distances where there would be no physical damage.

7.2 GENERAL SUMMARY

The results obtained from the test are briefly summarized below, without reference to the appropriate chapters or appendixes.

7.2.1 Effects on Personnel (See Fig. 7.1)

7.2.1.1 Interior Ionizing Radiations

Lethal dosage to 900 yd
Median lethal dosage to 1000 yd[1]
Serious radiation sickness to 1200 yd
Moderate radiation sickness to 1400 yd

7.2.1.2 Interior-wall and Interior-air Temperature

Insignificant beyond 1000 yd
Secondary importance at less than 1000 yd

7.2.1.3 Interior-air Pressure

Insignificant beyond 1000 yd
Secondary significance at less than 1000 yd

7.2.1.4 Accelerations

Insignificant at 1100 yd and beyond
Serious-to-fatal injuries to 900 yd

7.2.2 Effects on Materiel (See Fig. 5.13)

7.2.2.1 Maintenance Required

No maintenance required beyond 1000 yd
Field and organizational maintenance to 1000 yd
Field maintenance to 750 yd
Depot maintenance to 500 yd

7.2.2.2 General Statements

The majority of damage was limited to external accessories and appendages. The limited amount of major damage resulted from the overturning of two vehicles and the loss of a turret from another.

7.2.3 Effects on Combat Effectiveness of Tank and Crew

Vehicles and their crews will not be affected beyond 1600 yd. Vehicles and their crews between 1200 and 1600 yd will, in general, suffer no immediate disability and no fatalities; however, disability may occur up to 2 weeks after exposure.

Vehicles and their crews between 1000 and 1200 yd will suffer no immediate impairment of combat effectiveness. Crews will suffer 50 per cent fatalities from 2 to 12 weeks after exposure; disability will occur in 1 to 2 days.

Vehicles and crews between 800 and 1000 yd will suffer immediate combat disability. Crews may be expected to be casualties due to radiation. Vehicles may be restored to combat effectiveness by organizational maintenance.

Vehicles and crews within 800 yd will suffer immediate combat disability. Crews will be fatalities due to movement of vehicles and/or radiation.

Vehicles located between 500 and 800 yd may be recovered within 3 days and restored to complete combat effectiveness by field or base maintenance.

7.3 COMBAT EFFECTIVENESS OF ARMOR

7.3.1 Tactical Offense

In line with the statement that the most valuable portion of a medium tank is its crew, the minimum safe distance from an atomic explosion for such a weapon is determined by the effects on the crew. Figure 7.2 shows the distance vs yield for certain dosages for the most vulnerable member of the crew.

If 10 r is accepted as a tolerable dosage for an offensive crew in a combat situation, buttoned-up medium tanks can afford to be waiting, ready to attack, only 2100 yd from a 50-kt burst, or 1850 yd from a 20-kt burst. If 25 r is acceptable, these distances are reduced to 1800 and 1650 yd, respectively.

If attacking armor with an atomic weapon, it is desirable to know the damage which can be expected. Of course, data for only the medium tank are available at the time of this writing. Figure 7.3 shows the average dosage to be expected by the crew members in the hull and in the turret of a medium tank at various distances from a 50-kt bomb.

The use of the survival information in "The Effects of Atomic Weapons" was helpful in determining the survival chances for the average crew member, which are shown in Fig. 7.4. It is seen that the drivers are significantly better protected than the crew members in the turret. When the average driver has a 50 per cent chance of survival (400 r), the average tank commander has received a lethal dose (700 r). Furthermore, any member of the average crew will survive at distances which are fatal to unshielded personnel.

The probable combat effectiveness of a medium tank (vehicle alone) vs distance from the explosion is shown in Fig. 7.5.

7.3.2 Tactical Defense

When the data given in Sec. 7.3.1 are considered, it is obvious that, if the enemy is in a position to use atomic weapons against armored formations, the only immediately available defense is dispersion. Large concentrations of armor should be avoided, e.g., a battalion of 68 medium tanks in an assembly area. When each tank costs approximately $250,000, a battalion priced at $17,000,000 becomes a major target. In the formulation of principles for tactical use of atomic weapons, such questions should be considered.

7.4 RECOMMENDATIONS

The work which is reported in this volume should be continued by extension to other equipment and to different yields and burst locations.

REFERENCE

1. "The Effects of Atomic Weapons," p 343, Los Alamos Scientific Laboratory and U. S. Government Printing Office, 1950.

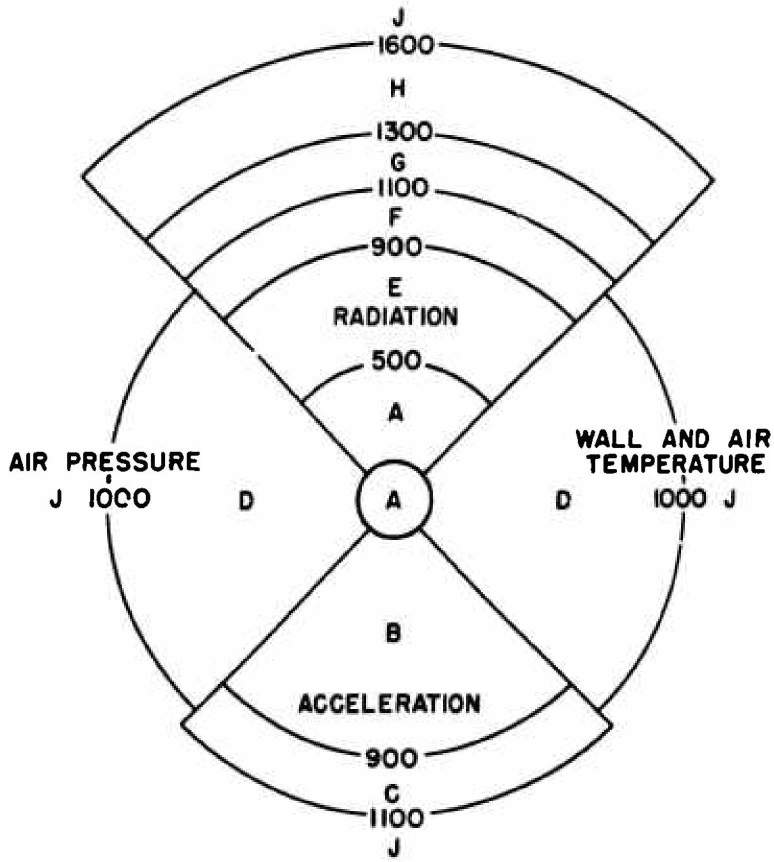


Fig. 7.1 Damage to Medium Tank Personnel at Various Distances in Yards from a 50-kt Bomb. Immediate effects: A, fatal; B, serious to fatal; C, moderate to serious; D, minor. Delayed effects: E, fatal; F, serious to fatal; G, moderate to serious; H, minor; J, no damage.

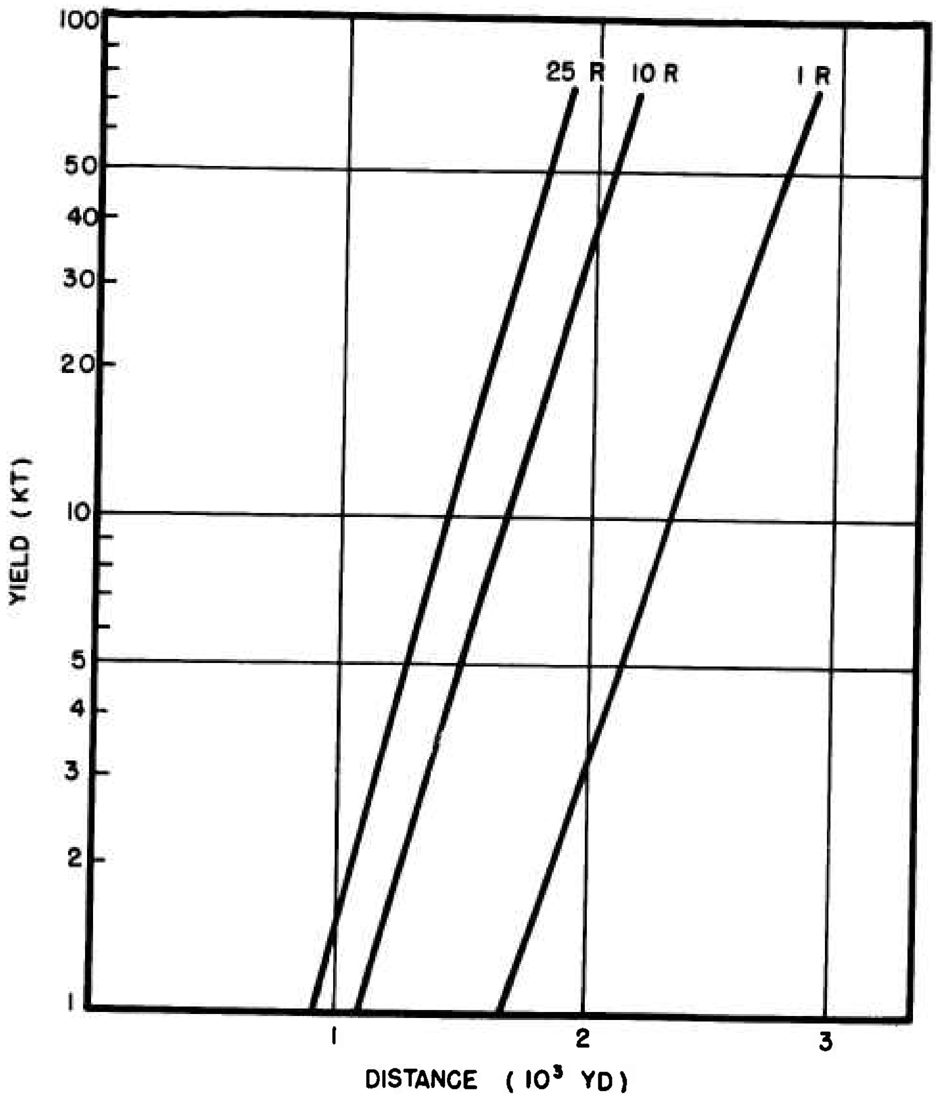


Fig. 7.2 Distance vs Yield for Tank Commander's Dosage of 1, 10, and 25 r

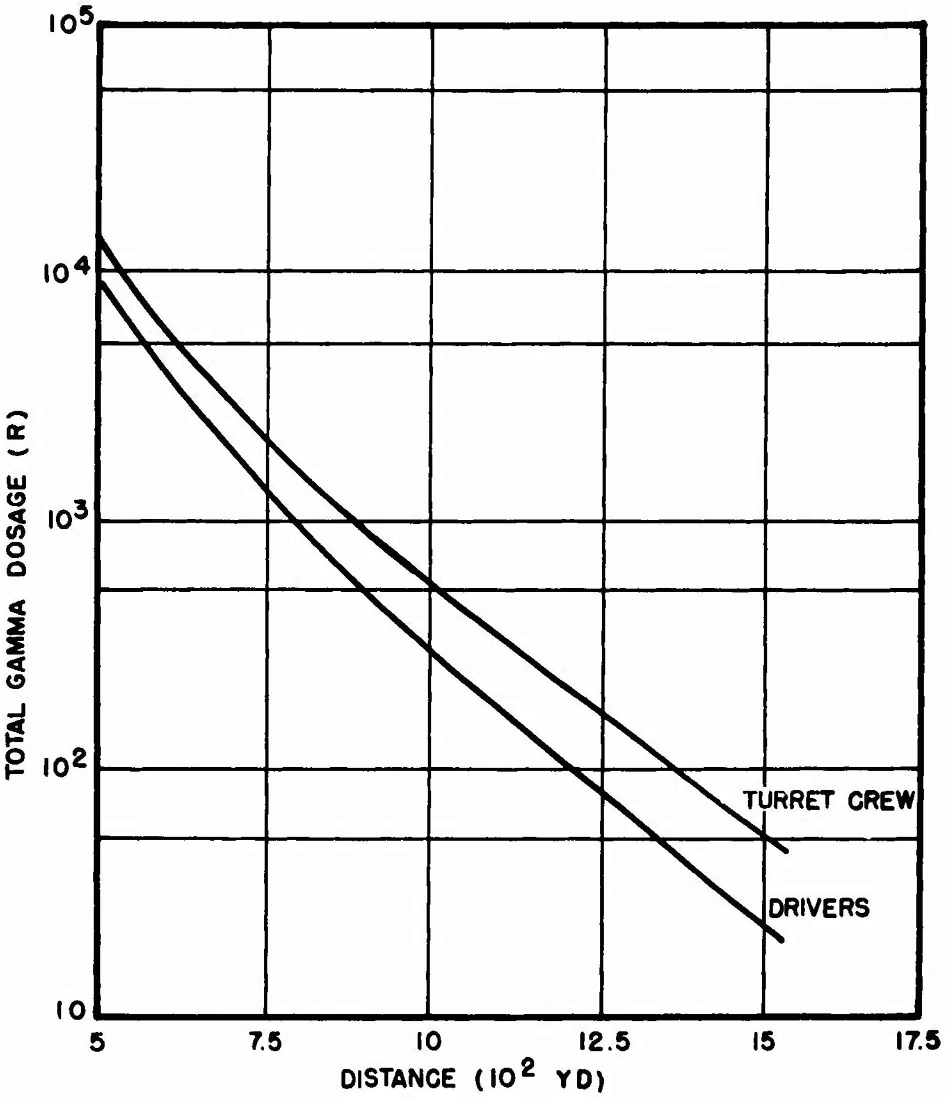


Fig. 7.3 Average Dosage of Drivers and Turret Crew as a Function of Distance from 50-kt Bomb

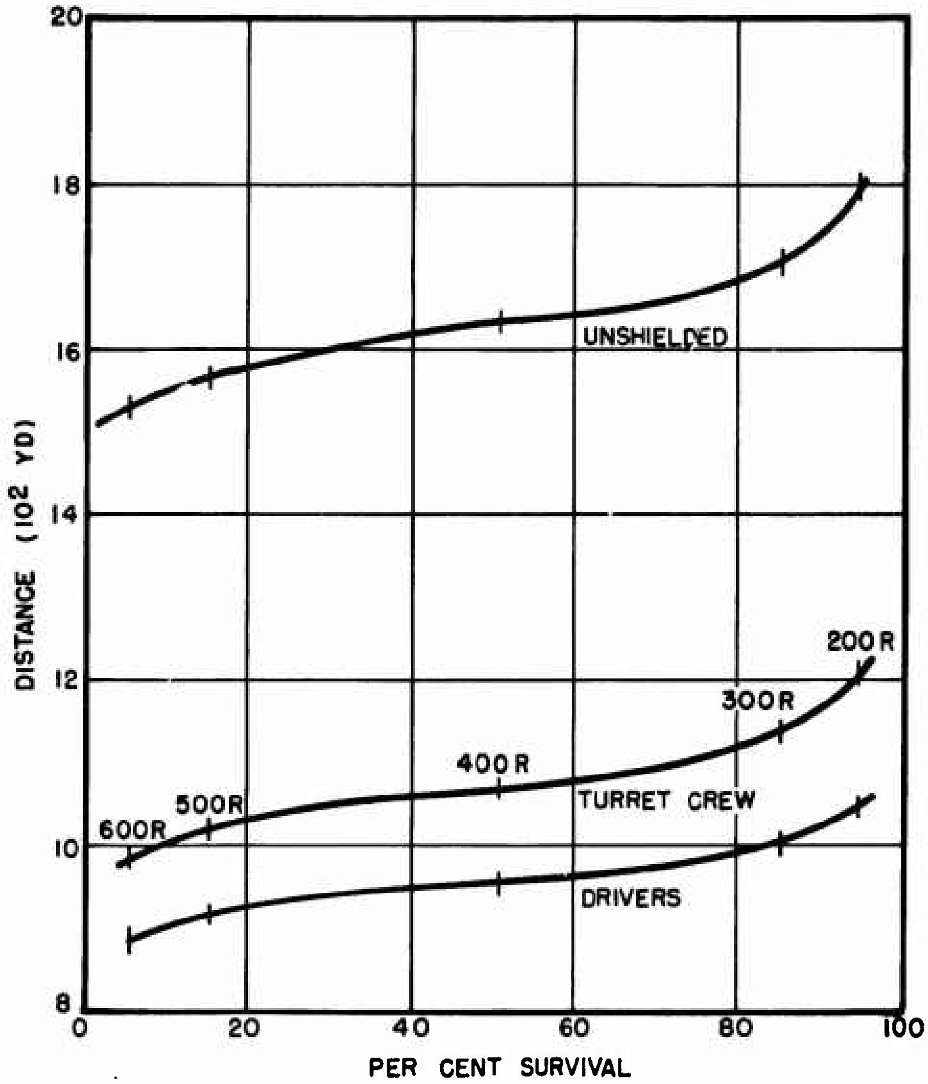


Fig. 7.4 Average Percentage Survival of Drivers and Turret Crew as a Function of Distance from 50-kt Bomb

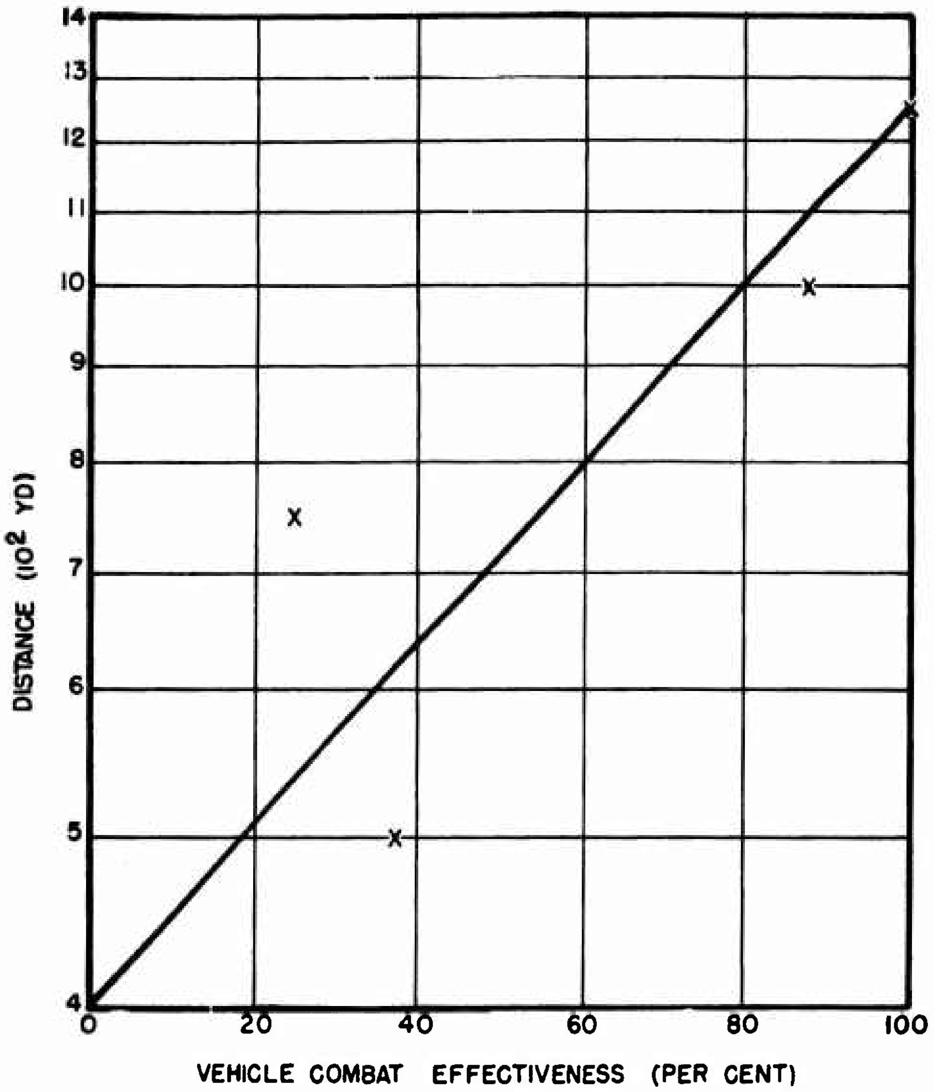


Fig. 7.5 Probable Combat Effectiveness of Medium Tanks as a Function of Distance from 50-kt Bomb

Appendix A

Instrumentation

A.1 GENERAL CONSIDERATIONS

A.1.1 Introduction

Chapter 4 contains a brief outline of the instrumentation used. This appendix is intended to provide a more comprehensive record of the instrumentation and operating techniques, along with some supplementary information which might be helpful in a similar program. It is not intended to be encyclopedic, however, and many details of design and development are omitted. References to sources of further information are supplied where possible.

The instrumentation program quite naturally resolved itself into the following phases:

1. Determination of individual types and numbers of measurements at the various vehicles
2. Design of instrumentation system
3. Selection and procurement of suitable recorders, gauges, and other major system components
4. Design and construction of control devices, gauges, and various smaller system components
5. Testing and calibration of all instrumentation
6. Preparation for the installation of the instrumentation in the test vehicles
7. Field installation and operation of instrumentation
8. Roll-up
9. Record playback and miscellaneous calibration testing necessary in the reduction of test data

The results obtained in Chap. 3 were used in accomplishing phase 1. Experience of BRL and others, notably Wright-Patterson Air Force Base and the Sandia Corporation, was useful for phases 2 and 3. Project 6.3 personnel accomplished phases 4, 5, and 6 at BRL. In connection with phase 6, support brackets, studs, and mounting plates were fabricated and welded to the inside walls and floors of the vehicles prior to shipment to the test site. Some smaller fittings were fabricated, and mounting holes were drilled at the test site. Phases 7 and 8 were of course accomplished at the test site by Project 6.3 personnel, and phase 9 was completed after the return to BRL.

This appendix deals with the instrumentation system which resulted from this program. The results obtained may be found in Chap. 5 and Appendix B.

A.1.2 Orientation of Test Vehicles

Figure A.1 and Table A.1 indicate the relative positions of the test vehicles. The positions were, in most cases, leveled with a bulldozer before the vehicles were emplaced. Some vehicles were initially placed in position no more than 5 yd from the surveyed positions in order to take advantage of the most suitable surface. It is estimated that the accuracy of angular orientation of the vehicles was of the order of ±1°.

A.1.3 General Description

The instrumentation system was based on two assumptions: (1) that a primary recording system would center about a multichannel magnetic tape recorder, and one such complete system would be assembled for each of several vehicles; and (2) that secondary recording systems, simpler in nature, would be employed

TABLE A.1 DATA PERTINENT TO FIELD ARRANGEMENT OF THE TEN TEST VEHICLES

Vehicle Position No.	Range from Ground Zero (yd)	Azimuth (deg, min, sec)*	Vehicle Serial No.
6311	500	276-00-00	USA 30 162 883
6312	500	280-00-00	USA 30 128 063
6321	750	262-49-00	USA 30 119 954
6322	750	260-31-00	USA 30 128 257
6323	750	265-07-00	USA 30 128 120
6331	1000	275-00-00	USA 30 128 117
6332	1000	273-00-00	USA 30 127 440
6341	1233	262-00-00	USA 30 162 872
6343	1233	259-42-29	USA 30 127 424
6351	1400	303-21-52	USA 30 127 418

*Measured clockwise from South with origin at ground zero.

where shock conditions were severe and would provide supplementary instrumentation at positions having tape recording systems.

For the primary recording system, 24-channel magnetic tape recorders, built by the Webster-Chicago Corp., were purchased. The secondary recording systems consisted of a wide variety of devices ranging from self-recording accelerometers to temperature-sensitive paint smears.

Table A.2 shows the total number of measurements of each type for each of the 10 vehicle positions. Figures A.2 to A.11 indicate by block diagrams the total instrumentation arrangement as finally installed and operated in each of the 10 test vehicles. Table A.10 is a breakdown of the ionizing radiation measuring devices for each venicle totaled in Table A.2. Table A.11 gives the sources of the various instruments used.

A.1.4 Time Signals

Time recording systems were designed to operate automatically in accordance with built-in programming, once the action had been initiated by timing signals provided at the test positions. These timing signals were in the form of relay contacts which were activated automatically at predetermined times with respect to zero time by a central timing station provided by Project 1.11. In addition, photocell units known as "Blue Boxes," which actuated relays at the flash of the weapon, were also provided by Project 1.11 at the test site. Table A.3 shows the timing signals which were provided for and used by Project 6.3 at the various test positions.

A.1.5 Installation of Instrumentation

Figures A.12 and A.13 show typical groups of equipment for two test vehicles except for dosimeters and phantoms. The various instruments indicated on Figs. A.2 to A.11 may be identified in these photographs.

In general, like instruments were mounted in similar positions in all test vehicles. Figures A.14 to A.19 show typical installations of the various pieces of equipment as completed at the test site. The locations of the various gauges in plan and elevation, except dosimeters, phantoms, and accelerometers, are shown in Fig. A.20. Dosimeter locations are shown in Fig. B.1, Appendix B. Phantoms were placed in the commander's and driver's seats. Figures A.21 to A.26 show in detail the locations and orientations of the accelerometers used in conjunction with the 24-channel magnetic tape recorders. Figure A.27 shows the positions of self-recording accelerometers used in seven of the test vehicles.

TABLE A.2 TOTAL NUMBERS AND TYPES OF MEASUREMENTS FOR WHICH INSTRUMENTATION WAS INSTALLED AND OPERATED IN EACH OF THE TEN TEST VEHICLES

Position No.	Range from Ground Zero (yd)	Ionizing Radiation		Acceleration		Air Pressure		Temperature			Turret Displacement
		Total Dosage	Time Function	Self-recording	Time Function	Peak	Time Function	Peak Wall*	Time Function (Wall)	Time Function (Air)	Scratch Gauge
6311 (M-46)	500	39	0	4	0	1	0	4	2	0	1
6312	500	38	0	4	0	1	0	4	2	0	1
6321	750	40	4	2	6	1	2	4	5	1	1
6322	750	41	0	2	0	1	0	5	0	0	0
6323	750	39	0	2	6	1	2	2	5	1	1
6331	1000	40	4	2	6	0	2	4	5	1	0
6332	1000	40	0	2	6	0	2	3	5	3	0
6341 (M-46)	1233	40	0	0	2	0	2	2	3	1	0
6343	1233	39	0	0	1	0	2	2	0	1	0
6351	1400	60*	0	0	0	0	0	3	0	0	0

*Includes measurements outside vehicle.

TABLE A.3 AUTOMATIC TIME CONTROL SIGNAL RELAYS AND BLUE BOXES USED TO CONTROL INSTRUMENTATION AT EACH OF THE FIVE RANGES FROM GROUND ZERO

Range from Ground Zero (yd)	−30-min Relay	−5-sec Relay	−1-sec Relay	Zero Relay (Blue Box)
500	1 (2)*	0	0 (1)	0
750	1 (4)	1 (2)	1 (2)	0
1000	1 (4)	1 (2)	0	1 (1)
1233	1 (2)	1 (1)	0	0
1400	0	0	0	0

*Numbers in parentheses indicate pairs of contacts; only "normally open" contacts were used. The −1-sec contacts for the 500-yd range were wired from relay at 750 yd.

The major instruments were mounted as shown in Figs. A.14 to A.19. The installation of dosimeters and phantoms presented a somewhat unusual problem. As mentioned in Chap. 4, rapid recovery was essential and was effected in the following manner.

Film packets and other small dosimeters were placed in men's socks, usually one to a sock, which were in turn suspended by a string from each end so that the dosimeter was in the desired location. One string from each sock led to a hatch which could be conveniently opened from the outside. These hatches were for the driver and commander. The commander's hatch was the final exit and was provided with outside locking. The driver's hatch was locked from the inside, but it could be unlocked from the outside by means of a steel cable from the latch to the outside through a hole drilled for this purpose. The other string on each sock was lighter and was fastened to the inside of the tank. The dosimeters were installed in the last 2 hr before evacuating the site and were recovered prior to H+6 hr. Recovery was effected by opening tne hatches and seizing and pulling on the strings affixed there. The lighter strings broke, and the socks with the dosimeters were recovered.

The phantoms were secured in the seats with web belting. They were provided with handles and were recovered at the same time as the dosimeters, after the belting was cut with a linoleum knife.

The positions of all accelerometers were carefully measured with respect to a point near the center of gravity. These measurements are shown in Figs. A.21 to A.27. The centers of gravity were obtained from the Automotive Division at Aberdeen Proving Ground, and it is estimated that the designated points lie within ±2 in. of the true center of gravity. Measurements were made to ±0.3 in.

Accelerometers were installed and connected in such a manner that, when the vehicle moved in the direction indicated by the small arrows at each accelerometer position shown in Figs. A.21 to A.27, the sign of the resulting signal was positive on the final record. This corresponded to a defined positive acceleration of the tanks in a coordinate system based on each tank in all cases except those marked by a negative sign on the figures. The coordinate system used in Appendix B differs in that it is relative to the burst point.

A.2 PRIMARY RECORDING SYSTEM

A.2.1 Recorder and Playback Equipment

Equipment similar to that described in this section was used in Projects 3.4, 8.1, and 8.2. The 24-channel magnetic tape recorder consisted of 2 major components: (1) a gauge amplifier unit containing 24 individual gauge amplifiers and an oscillator gauge power supply, and (2) a recording unit containing a dynamotor power supply, two tape reels, 24 recording heads, and other associated equipment. Figure A.28 shows these two recorder components with the cover removed from the recording

mechanism. The 24 recording heads are located in the enclosure on the far side of the recording mechanism. Provision is made in the recording mechanism for the controlling and programming of recording time by means of suitable external circuitry.

The playback equipment consists of one 7-ft relay rack which contains a control panel, a playback mechanism for handling the magnetic tape, and two separate playback amplifiers. Figure A.29 shows the playback equipment with the dust cover in place over the two playback amplifiers. This equipment permits playback of any two of the 24 recorded channels simultaneously when used with auxillary graphic recording equipment. The complete playback equipment setup is shown in Fig. A.4. The two a-c electronic voltmeters and the cathode-ray oscilloscope shown beside the playback rack are used for monitoring purposes. Two d-c amplifiers are used in conjunction with the 2-channel strip chart recorder. (The 2-channel recorder and associated d-c amplifiers as used with the 24-channel playback equipment were manufactured by the Brush Development Co., Cleveland, Ohio.)

A.2.2 Control Unit

The control unit used for operating the 24-channel magnetic tape recorders during the test was designed and constructed at BRL; two of these units are shown in Fig. A.30. The front view of one shows the various switches used to test the unit, preset for initial conditions. The rear view of the second unit, with the cover removed, shows the two timing motors used (at the left), and associated cam-operated micro switches. A stepping relay is located in the center, with various other control relays at the right. Figure A.31 is a schematic wiring diagram of the control units. In this diagram, control cams A and B, and associated micro switches, are shown in approximate starting positions. Several test and preset switches are omitted from Fig. A.31 for the sake of simplicity. Each of the control units was tested and preset, then connected to timing signals, provided as indicated in Fig. A.31, just prior to test time.

At test time the recorders were operated by the control units which, in conjunction with the provided time signals, turned on filament, plate, and gauge supplies at H–30 min for warm-up. They recorded for a 2-min period starting at H–5 sec and shut off all recording equipment; they then turned on equipment for a 5-sec recording period starting approximately each hour after zero, with a half hour warm-up prior to each recording period.

A calibration pulse signal was provided in the middle of each 5-sec recording period for each channel by causing the control unit to energize simultaneously a relay in each impedance gauge recording channel. The relay contacts were connected so as to provide a known unbalance in the input circuit and give a known reference level on the recorder output. This reference provided a sensitivity calibration for the entire recording system from the input of the 24-channel tape recorder to the final output from the playback equipment.

A.2.3 Recorder, Theory of Operation

The 24-channel tape recording system is unique in that it employs a method of phase modulation referenced to a recorded fixed frequency and in this manner avoids numerous drawbacks of the more conventional amplitude recording techniques. In operation the gauge head is connected to a suitable coupling unit which is, in turn, connected to one of the 24 individual amplifier channels. The gauge and a coupling unit form a bridge circuit, complete with balancing controls, which obtains its supply voltage from the common 3750-cycle oscillator in the amplifier unit and delivers its output to one of the individual gauge amplifiers. The output of the individual gauge amplifier is, in turn, connected to one of the magnetic recording heads in the recording mechanism.

A block diagram of the complete recording system is shown in Fig. A.32. The gauge supply oscillator is common to all 24 channels, as are the 5-position selector switch in its output and the 24-position selector switch for vacuum-tube voltmeter. In Fig. A.28 these two selector switches can be seen on the top of the gauge amplifier chassis. All other components in Fig. A.32 are repeated for each channel. The "balance controls and attenuator" is elsewhere referred to as a coupling unit. The 5-position selector switch is used in the procedure for balancing gauge circuits and for prerecording data which are later used in adjusting the play-

back equipment at the time of final data playback. The vacuum-tube voltmeter is used for initial balancing of gauge inputs (bridge circuits).

Simplified block and vector diagrams of the recording system are shown in Fig. A.33.

The gauge power supply contains a stable oscillator and a power amplifier capable of supplying power to all the gauges of the system. The quadrature voltage generator receives its signal from the gauge power supply and furnishes the gauge amplifier a voltage shifted 90° in phase relative to the gauge input and output voltages. The principal circuit of the quadrature voltage generator is a phase-shifting circuit. The reference voltage generator also receives input from the gauge power supply and furnishes the gauge amplifier with a voltage having twice the frequency of the gauge input voltage. The principal constituent of the reference voltage generator is a frequency doubler.

From the vector diagram, Fig. A.33, it is seen that the reference voltage, E_R, and the quadrature voltage, E_q, are fixed in amplitude and phase, whereas the gauge output voltage, E_o, is of varying amplitude and is either in phase or 180° out of phase with the gauge input voltage. The varying gauge output voltage, the amplitude of which is proportional to the measured data, combines with the quadrature voltage to form resultants E_r', E_r'', etc., at angles θ', θ'', etc., respectively, with the quadrature voltage. The signal applied to the magnetic recording tape is the arithmetic sum of E_r and E_R, the reference voltage.

If the magnitudes of the components of E_r change by the same factor, E_r will change in the same proportion. However, the angle θ will be determined solely by the value of the data. Since θ is fixed with respect to extraneous amplitude variations, the playback equipment is designed to be sensitive to θ only. Full-scale range of the angle θ is limited to ±50°.

A.2.4 Playback, Theory of Operation

Figure A.34 gives a simplified block diagram of the 2-channel playback equipment used for reproducing records taken with the 24-channel magnetic tape recorder.

The output of a playback head is passed through filters which separate E_R from E_r, and the latter is doubled in frequency. After this operation the phase-modulated signal voltage and the reference voltage exist in separate circuits, both at twice the frequency of the gauge supply voltage in the recording equipment. Sharp pulses are derived from these voltages, and they each trigger one grid of an Eccles-Jordan flip-flop circuit. The duty cycle of the resulting rectangular wave is proportional to the instantaneous phase displacement θ of the E_R and E_r. A low-pass filter following the Eccles-Jordan element passes frequencies corresponding to data variations at an amplitude proportional to the tangent of its input. The output of the tangent circuit is therefore an exact replica of the gauge output voltage E_o. A stabilized low-impedance d-c amplifier is provided for the operation of a graphic recorder.

The four smallest blocks in Fig. A.34 represent controls used for adjustment of the playback system in conjunction with the prerecord data at the start of the tape as mentioned in Sec. A.2.3.

Figure A.40 shows the entire playback system setup. Figures A.41, A.42, and A.43 show the playback mechanism, the playback control panel, and one of the two playback amplifiers, respectively. Figure A.43 is a front view of the playback amplifier and shows wiring detail at the tube sockets and other components. This is one of the two playback amplifiers as they appear directly behind the dust cover in the lower portion of the relay rack shown in Fig. A.29.

A.2.5 Gauge Amplifier Diagram

Figure A.35 shows in schematic form the principal circuitry of an entire recording channel from the amplifier input connector of an individual gauge amplifier to the corresponding recording head. This diagram proved particularly useful in the field because it includes all the information concerning adjustments and circuit components which is normally required in using or servicing the recording equipment. Modifications to the amplifiers were necessary for use with resistance-wire temperature gauges; these modifications are shown in the block at the bottom of Fig. A.35. The common gauge supply oscillator is shown only in sufficient detail to indicate adjustments and method of obtaining quadrature and reference voltages.

A.2.6 Adjustments, Alterations, and Accuracy of 24-channel Recorder

The 24-channel magnetic tape recorders used on this project were a new development put to field use for the first time during the 1951 tests at Eniwetok Atoll, and many alterations and refinements had to be made before the equipment would operate satisfactorily. Considerable effort went into alignment and adjustment of the magnetic heads in each of the recorders and the playback mechanism before satisfactory signal levels could be consistently obtained. A number of the magnetic heads were found to be defective after a relatively short time and had to be interchanged with those from the several unused channels.

Trouble was experienced with the burning out of gauge amplifier output transformers as a result of shorting within the particular type of 0.01-μf condenser used as coupling between the two stages (see Fig. A.35). Since new transformers were not readily available, it was found desirable to replace the marginal coupling capacitors with units having a high voltage rating.

Another source of trouble was found in the input transformers of the gauge amplifiers (see Fig. A.35). Different transformers permitted widely different phase shifts of the gauge signal between the amplifier input connector and the grid of the first stage. Since the quadrature voltage is common to all 24 channels of one recorder, it had to be adjusted to an average 90° shift from the several different signal phase angles. This condition was considerably alleviated by using the amplifiers which were determined to be most similar in the phase shift characteristic.

Circuit changes were made in the input circuit of each of the amplifiers used with the resistance-wire temperature gauges. The details of this change are shown in the diagram at the bottom of Fig. A.35.

Based on various performance tests and a knowledge of the measuring techniques employed, it is believed that measurements made with the 24-channel magnetic tape equipment are accurate to ±10 per cent.

A.2.7 Gauge and Calibration Data

Tables A.4 to A.8 give setup and calibration data for all channels of the five 24-channel tape recorders operated on this project. The column "Attenuator Setting" applies only to accelerometers and pressure gauges, since it pertains to the attenuator switch position of the companion coupling units (see Fig. A.36). The column "Sensitivity, Full Scale" pertains to over-all recording sensitivity from gauge to magnetic tape. The sensitivity can be increased in the playback system to the full extent permitted by the amplitude of recorded data. Any resulting increase in effective scale length provides better over-all accuracy of playback data. Complete detailed over-all calibration data were provided for each channel by the combination of the required prerecord data recorded on the beginning of the tape at the time of final gauge-recorder adjustments and a detailed over-all calibration characteristic as previously determined under laboratory conditions for each complete gauge and recording system.

It will be noticed in Figs. A.9 and A.10 and Table A.8 that one of the five recorders was operated with gauges in two different vehicles. The two vehicles were approximately 100 ft apart, and cables of three-wire shielded microphone cable were connected between the gauges and respective coupling units (containing remainder of bridge circuit and necessary balancing components) in the other vehicle. No difficulties were experienced by so splitting the measuring bridge-circuit components.

A.2.8 Coupling Units for Accelerometers and Pressure Gauges

Impedance type gauges, i.e., accelerometer and pressure gauges, were used in conjunction with individual coupling units purchased from Wiancko Engineering Company, Altadena, Calif. Figure A.36 shows two of these coupling units with opposite side covers removed. One is pictured from the front, showing the 20-position step attenuator switch and the two bridge balancing controls; the second is photographed from the rear, showing the three electrical connectors for connecting to the gauge and to the gauge amplifier, as well as to the coil of the calibration relay. In the recording system block diagram of Fig. A.32 the impedance gauge coupling unit is indicated as Balance Controls and Attenuator.

Table A.9 shows the approximate full-scale range of the recording system for the different

TABLE A.4 RECORDER DATA FOR POSITION 6321, VEHICLE NO. 954, 24-CHANNEL MAGNETIC TAPE RECORDER NO. 37

Gauge	Gauge Location*	Recorder Channel	Attenuator Setting	Sensitivity, Full Scale
Radiation	R1	21		1200 r/hr
Radiation	R2	20		1200 r/hr
Radiation	R3	18		1200 r/hr
Acceleration	Pos. 1	11	3	3.25 g†
Acceleration	Pos. 2	14	9	7.5 g
Acceleration	Pos. 3	13	9	35.4 g
Acceleration	Pos. 4	15	3	3.25 g
Acceleration	Pos. 5	10	13	16.9 g
Acceleration	Pos. 6	17	8	32.3 g
Pressure	P1	6	12	10.4 psi
Pressure	P2	7	11	10.4 psi
Air temperature	AT1	1		20–100°C
Wall temperature	WT1	2		20–60°C
Wall temperature	WT2	24		20–60°C
Wall temperature	WT3	4		20–60°C
Wall temperature	WT4	8		20–60°C
Wall temperature	WT5	23		20–60°C

*Figure A.20 shows positions of radiation monitors, pressure gauges, and temperature gauges; Fig. A.21 shows accelerometer positions.

†As used in this table, g refers to sea-level gravity acceleration (32 ft/sec^2).

attenuator settings as calculated from the manufacturer's data for the two types of accelerometers and the pressure gauge. The calculations are determined by the amount of signal required at the gauge amplifier input to develop a 50° phase shift which represents full-scale input of the amplifier. Calculations for attenuator steps beyond 14 have no use because maximum physical rating of the gauges is exceeded at this point.

Figure A.37 shows the schematic wiring of the impedance gauge coupling unit, including input from the gauge and output to the gauge amplifier.

The features of the impedance gauge coupling unit are as follows:

1. Together with the gauge head it forms a complete balanced bridge circuit conventional to carrier-modulated bridge-circuit measuring techniques.

2. It contains phase and amplitude balance controls for initial balancing of the bridge output to zero under conditions of zero pressure (or acceleration) at the gauge.

3. It contains a calibration transformer which is connected through the contacts of the calibration relay so as to unbalance the bridge circuit a known amount whenever the relay is energized, and thus provide the calibration step during each 5-sec recording time for monitoring recorder operation.

4. It provides a step attenuator for initial selection of bridge-circuit output sensitivity in accordance with the approximate levels shown in Table A.9.

A.2.9 Temperature-gauge Balancing Units

Balancing of resistance-wire temperature gauges is provided by a common 7-channel balancing unit at each 24-channel tape recorder. Coupling units for these gauges were manufactured at BRL. Figure A.38 shows one of these balancing units built into a shock-mounted

TABLE A.5 RECORDER DATA FOR POSITION 6323, VEHICLE NO. 120, 24-CHANNEL MAGNETIC TAPE RECORDER NO. 41

Gauge	Gauge Location*	Recorder Channel	Attenuator Setting	Sensitivity, Full Scale
Acceleration	Pos. 1	10	12	16 g†
Acceleration	Pos. 2	11	10	9.6 g
Acceleration	Pos. 3	13	3	3.3 g
Acceleration	Pos. 4	14	5	25.3 g
Acceleration	Pos. 5	15	10	9.0 g
Acceleration	Pos. 6	17	3	3.3 g
Pressure	P1	6	12	11.2 psi
Pressure	P2	7	12	11.2 psi
Air temperature	AT1	1		20-100°C
Wall temperature	WT1	2		20-60°C
Wall temperature	WT2	4		20-60°C
Wall temperature	WT3	8		20-60°C
Wall temperature	WT4	23		20-60°C
Wall temperature	WT5	24		20-60°C

*Figure A.20 shows positions of pressure gauges and temperature gauges; Fig. A.22 shows accelerometer positions.

†As used in this table, g refers to sea-level gravity acceleration (32 ft/sec^2).

TABLE A.6 RECORDER DATA FOR POSITION 6331, VEHICLE NO. 117, 24-CHANNEL MAGNETIC TAPE RECORDER NO. 38

Gauge	Gauge Location*	Recorder Channel	Attenuator Setting	Sensitivity, Full Scale
Radiation	R1	18		1200 r/hr
Radiation	R2	20		1200 r/hr
Radiation	R3	21		1200 r/hr
Acceleration	Pos. 1	10	3	3.2 g†
Acceleration	Pos. 2	11	7	6.4 g
Acceleration	Pos. 3	13	13	13.8 g
Acceleration	Pos. 4	14	3	3.4 g
Acceleration	Pos. 5	15	10	10.3 g
Acceleration	Pos. 6	17	13	14 g
Pressure	P1	6	7	5.4 psi
Pressure	P2	7	7	5.4 psi
Air temperature	AT1	1		20–60°C
Wall temperature	WT1	2		20–60°C
Wall temperature	WT2	4		20–60°C
Wall temperature	WT3	8		20–60°C
Wall temperature	WT4	23		20–60°C
Wall temperature	WT5	24		20–60°C

*Figure A.20 shows positions of radiation monitors, pressure gauges, and temperature gauges; Fig. A.23 shows accelerometer positions.

†As used in this table, g refers to sea-level gravity acceleration (32 ft/sec^2).

TABLE A.7 RECORDER DATA FOR POSITION 6332, VEHICLE NO. 440, 24-CHANNEL MAGNETIC TAPE RECORDER NO. 39

Gauge	Gauge Location*	Recorder Channel	Attenuator Setting	Sensitivity, Full Scale
Acceleration	Pos. 1	10	7	6.24 g†
Acceleration	Pos. 2	11	7	6.12 g
Acceleration	Pos. 3	13	3	2.97 g
Acceleration	Pos. 4	14	10	11.5 g
Acceleration	Pos. 5	15	7	5.7 g
Acceleration	Pos. 6	17	3	3.76 g
Pressure	P1	6	8	6.23 psi
Pressure	P2	7	8	6.23 psi
Air temperature	AT1	1		20–60°C
Wall temperature	WT1	2		20–60°C
Wall temperature	WT2	4		20–60°C
Wall temperature	WT3	8		20–60°C
Wall temperature	WT4	23		20–60°C
Wall temperature	WT5	24		20–60°C

*Figure A.20 shows positions of pressure gauges and temperature gauges; Fig. A.24 shows accelerometer positions.

†As used in this table, g refers to sea-level gravity acceleration (32 ft/sec^2).

TABLE A.8 RECORDER DATA FOR POSITIONS 6343* AND 6341, VEHICLES NO. 424 AND 872, 24-CHANNEL MAGNETIC TAPE RECORDER NO. 40

Vehicle Position	Gauge	Gauge Location†	Recorder Channel	Attenuator Setting	Sensitivity, Full Scale
6343	Acceleration	Pos. 1	15	10	12.3 g‡
6343	Pressure	P1	10	5	2.65 psi
6343	Pressure	P2	11	5	4.68 psi
6343	Air temperature	AT1	1		20–60°C
6341	Acceleration	Pos. 2	13	8	5.46 g‡
6341	Acceleration	Pos. 3	14	13	16.1 g‡
6341	Pressure	P1	6	5	4.61 psi
6341	Pressure	P2	7	6	3.32 psi
6341	Air temperature	AT1	2		20–60°C
6341	Wall temperature	WT2	4		20–60°C
6341	Wall temperature	WT3	8		20–60°C
6341	Wall temperature	WT4	23		20–60°C

*Recorder located at vehicle position 6343.

†Figure A.20 shows positions of pressure gauges and temperature gauges; Figs. A.25 and A.26 show accelerometer positions.

‡As used in this table, g refers to sea-level gravity acceleration (32 ft/sec^2).

TABLE A.9 APPROXIMATE FULL-SCALE RANGES OF ACCELEROMETERS AND PRESSURE GAUGES AT DIFFERENT ATTENUATOR SETTINGS (AT COUPLING UNIT) FOR 24-CHANNEL MAGNETIC TAPE RECORDING SYSTEM

Attenuator Step	Pressure Gauge (20 psi Max)	Accelerometer 20 g Max*	100 g Max*
0	2.0	2.0	10.0
1	2.4	2.4	11.9
2	2.8	2.8	14.1
3	3.4	3.4	16.8
4	4.0	4.0	20.0
5	4.7	4.7	23.7
6	5.6	5.6	28.2
7	6.7	6.7	33.5
8	8.0	8.0	39.8
9	9.5	9.5	47.3
10	11.3	11.3	56.2
11	13.4	13.4	66.8
12	15.9	15.9	79.4
13	18.9	18.9	94.4
14	22.5	22.5	112

*As used in this table, g refers to sea-level gravity acceleration (32 ft/sec^2).

chassis. Each channel contains phase and amplitude bridge balancing controls as well as input and output connectors. In the case of the resistance-wire temperature gauges, all four bridge-circuit elements (active and inactive) are mounted on the gauge. The schematic diagram in Fig. A.39 shows wiring of one channel of the balancing unit, as well as gauge input circuit and output connections to the gauge amplifier.

A.3 SECONDARY RECORDING AND GAUGE DETAILS

A.3.1 Radiation Measurements

Table A.10 shows the various types and numbers of devices used for ionizing radiation measurements within each of the 10 vehicles, including those used outside the vehicle at the 1400-yd position. Further details of these devices (except the radiation monitor and the telemetering monitor), together with figures showing locations, are included in Appendix B. Sources for the various instruments used are given in Table A.11.

A.3.2 Ionizing Radiation Monitor

A total of six model K-357 radiation monitors were used—three with each of two 24-channel tape recorders as shown in Figs. A.4 and A.7. These devices were manufactured especially for Project 6.3 by The Kelley-Koett Mfg. Co. of Cincinnati. Figure A.44 shows one of these instruments shock-mounted on a steel mounting plate which was in turn bolted to the floor of the vehicle. The three operating controls, the monitoring meter, and the three electrical connectors are plainly visible. One of the connectors is for input, one is for output, and the third is used for closing the tube filament circuits, proving remote operation. The large cylinder on top contains the ionization chamber.

The schematic diagram in Fig. A.45 shows the circuit complete except for a feature which provides for checking battery voltages on the indicating instrument by means of one of the panel selector switches. The instrument design is conventional except that the output circuit is modified to permit use directly with the 24-channel magnetic tape recorders. Figure A.45

TABLE A.10 TOTAL IONIZING RADIATION MEASUREMENTS FOR EACH OF THE TEN TEST VEHICLES

Vehicle Position No.	Low-Med. Range Film Packet (2 Films per Pack)	High-range Film Packet	Polaroid Dosimeter	Radiophotoluminescent Dosimeter, 20 to 30,000 r	Neutron-flux Indicators	Experimental Packets (Signal Corps)	Phantoms	Keleket	Telemetering
6311 (M-46)	3	25	6	4*	0	1	0	0	0
6312	3	25	6	4*	0	0	0	0	0
6321	18	10	6	4*	0	0	2	3	1
6322	18	10	6	4*	2	1	0	0	0
6323	18	10	6	4*	0	0	1	0	0
6331	28	0	6	4*	0	0	2	3	1
6332	28	0	6	4*	2	0	0	0	0
6341 (M-46)	28	0	6	4*	0	0	2	0	0
6343	28	0	6	4*	0	0	1	0	0
6351	28†	0	6	4*	0	0	2	0	0
Control pack outside vehicle	10	0	0	10	0	0	0	0	0

*Includes one outside lead container for calibration purposes.
†Includes nine sets submersed in water inside individual thermos bottles for calibration purposes.

TABLE A.11 INSTRUMENTATION USED ON PROJECT 6.3

Item No.	Instrument	Used with Item No.	Manufacturer's Nomenclature	Source
1*	24-channel tape recorder	2	Recording mechanism, model 50013	WC
2*	24-channel amplifier	1	Gauge amplifier chassis, model 50026	WC
3	Accelerometer	2	Accelerometer, types 3AA 20-A, 3AA 100-A	W
4	Pressure gauge	2	Pressure gauge, model 3 PAD 20-A	W
5	Radiation monitor	2	Radiation monitor, model K357	K
6	Air-temperature gauge	2	Air temperature gauge, BRL-M	BRL
7	Wall-temperature gauge	2	Wall temperature gauge, BRL-M	BRL
8	Coupling unit, impedance	2, 3, 4	Model 3CPI-A	W
9	Coupling unit, resistance	2, 6, 7	Coupling unit, resistance, BRL-M	BRL
10	Control unit	2	Control unit, W/C, BRL-M	BRL
11	D-c recorder	2	Recorder, model 71B	S
12	D-c amplifier-recorder	6, 7	Recorder, model 71A	S
13	Calibration unit	12	Control unit, S, BRL-M	BRL
14	Self-recording accelerometer		Accelerometer, type 2040 Al	ERA
15	Blue Box	14	Blue Box, type A-1	EG&G
16	Foil-rupture gauge		Gauge, foil rupture	BRL
17	Temperature-sensitive paint		Tempilag	T
18	Temperature-sensitive capsule		Tempilstiks	T
19	Scratch gauge			BRL
20	Film badge, high range		Film badge type 548-0, single emulsion	EK
21	Film badge, medium and low range		Unknown	NBS
22	Polaroid dosimeter		Dosimeter DT-65	SCEL
23	Radiophotoluminescent dosimeter		Unknown	NRL
24	Phantom		Unknown	NMRI
25	Telemetering radiation monitor		Radiac equipment AN/USQ-1	BA
26	Neutron-flux indicators		Unknown	LASL
27	Experimental packet, radiation		Unknown	SCEL

Explanation of Source Abbreviations

BA	Bureau of Aeronautics, Department of the Navy, Washington 25, D. C. (Project 5.2)
BRL	Ballistic Research Laboratories, Aberdeen Proving Ground, Md.
EG&G	Edgerton, Germeshausen & Grier, Inc., 160 Brookline Ave., Boston 15, Mass. (Project 1.11)
EK	Eastman Kodak Co., Rochester, N. Y.
ERA	Engineering Research Associates, 1902 W. Minnehaha Ave., St. Paul, W4, Minn.
K	Kelley-Koett Mfg. Co., The, 930 York St., Cincinnati 14, Ohio
LASL	Los Alamos Scientific Laboratory, Los Alamos, N. Mex. (Project 1.5)
NBS	National Bureau of Standards, Washington, D. C. (Project 1.2)
NMRI	Naval Medical Research Institute, Bethesda, Md. (Project 2.4)
NRL	Naval Research Laboratory, Washington 25, D. C.
S	Sanborn Co., 39 Osborn St., Cambridge 39, Mass.
SCEL	Signal Corps Engineering Laboratories, Evans Signal Laboratory, Fort Monmouth, N. J. (Project 5.1)
T	Tempil Corporation, 132 West 22nd St., New York 11, N. Y.
W	Wiancko Engineering Company, 2670 North Fair Oaks, Altadena, Calif.
WC	Webster-Chicago Corp., 5610 Bloomingdale Ave., Chicago 39, Ill.

*These items, plus the playback equipment, comprise the magnetic data-recording system, model 1000.

also shows the manner of connecting the 3750-cycles/sec bridge input from the gauge oscillator supply and the method for obtaining modulated output for the gauge amplifier channel. In operation the amplifier input circuit is balanced by the original gauge amplifier controls (R2 and R5, Fig. A.35) by observing zero dip on the output meter when the radiation monitor panel indicator is adjusted for zero indication by the zero panel control (R16 in Fig. A.45).

A.3.3 Ionizing Radiation Monitor, Telemetering

Project 5.2 furnished AN/USQ-1 (XN-1) radiac equipment for installation in the test vehicles at positions 6321 and 6331. The measurements of ionizing radiation rates telemetered by these units were recorded during the test by Project 5.2, and complete details on this instrument can be secured from that Project. The instrument may be seen in Fig. A.17, item 3, and Fig. A.18, item 2, as well as in its installed position in Fig. A.19, item 3. For use in the test vehicles, it was necessary to modify the instrument by separating it from its antenna and providing suitable matching.

A.3.4 Accelerometer, Self-recording Type

A self-recording accelerometer manufactured by Engineering Research Associates, Minneapolis, was used in this project as a secondary means of obtaining vehicle acceleration data. Similar units were also used by Projects 1.6 and 3.4. One of these devices is shown as item 6 in Fig. A.12. Figures A.46 to A.48 show details of the instruments, and Fig. A.49 shows the associated mechanical and electronic equipment used in preparation of tapes and record playback. As stated in Sec. A.1.5, the self-recording accelerometers were installed in seven of the test vehicles as indicated in the location diagram and table of Fig. A.27.

The self-recording accelerometer consists essentially of a spring-driven three-channel magnetic tape recorder with two accelerometer recording heads called seismic elements, which are oriented to record accelerations along axes at right angles to each other, and one timing signal head called a "torsion timer." Figures A.46 and A.47 show details of these accelerometers. Each of the two seismic elements consists of a tiny permanent magnet mounted at the end of a leaf spring to form a mass-spring system. The torsion timer contains a similar magnet on the end of a counter-balanced lever suspended on a wire at the center. The wire is clamped at its ends and acts as a torsion spring. During recording, each permanent-magnet head moves in and out from the tape, partially erasing a carrier signal (1280 cycles/sec) which has been previously recorded on each of the three channels of carrier signal, amplitude modulating (by partial erasing) in accordance with the motion of the seismic elements and torsion timer.

The magnetic tape is on a plastic base and measures $^3/_4$ in. wide by about 5 ft long; 3 ft of this tape is used for recording. Each of the erasing magnets measures about 0.010 in. thick (along tape) by 0.120 in. wide (across tape) and is adjusted to rest about 0.003 in. from the tape surface over its respective channel. The tape is loaded onto the drag spool (Figs. A.46 and A.47) which contains a fluid drag-cup arrangement for controlling the tape speed. The tape speed can be adjusted between approximately 4 and 9 in./sec. The tape is then threaded around the recording spool and over the idler spool to the drive spool which contains the driving spring. Figure A.47 shows a tape loaded and ready for recording.

In operation the drag spool and torsion timer are held in starting position against the forces of the drive spring and torsion spring, respectively, by two locking pins as indicated in Fig. A.48. A tip spring, shown in Fig. A.47, is connected to one of the pins and holds the torsion timer in a cocked position. As shown in Fig. A.48, the two pins are held against their own spring loading by a two-piece trigger spring which is held by a fuse wire. To fire the accelerometer it is simply necessary to blow the fuse wire by an external power source (batteries or other).

The mechanical playback unit shown in Fig. A.49 is used for prerecording of the carrier frequency on the tape as well as for later playback of the amplitude-modulated signal. The tape mounts around the outer edge of the turntable. The single head can be adjusted to any one of the three channel positions and is used for both recording and reading. The electronic display unit contains a cathode-ray tube and is used for visually observing any portion of the tape with any one of several available time scales, using different horizontal sweep times.

Recording is accomplished by photographing the cathode-ray tube. Other forms of recording, using magnetic oscillograph equipment, can be used by making minor circuit modifications in the electronic display unit. The power supply unit operates from 115 v, 60 cps, and supplies all power for the mechanical playback unit and the electronic display unit.

Based on experience and tests, it is believed that accuracy of acceleration measurements taken with the self-recording accelerometers is within about ±20 per cent of full scale.

A.3.5 Accelerometer, Impedance Type

Figure A.50 shows three of the impedance type accelerometer gauges (manufactured by Wiancko Engineering Company, Altadena, Calif.) that were used with the 24-channel magnetic tape recorder. Similar gauges were also used by Projects 3.4 and 8.1. The gauge shown at the lower left in Fig. A.50 is assembled and ready for use. The one at top center is shown with the entire gauge-element assembly removed, along with a single O-ring gasket. The gauge at the right is shown partially disassembled from the flange end with the gauge element still in place. When the gauge is properly assembled with the O ring and the steel retainer ring, the transparent diaphragm and two metal disks shown with the gauge at the right in Fig. A.50 provide for thermal expansion of the damping oil.

The gauge element consists of two coils and associated magnetic circuits. An armature is spring-mounted in close proximity to the coils so as to complete the two magnetic circuits. A small weight attached to one end of the armature completes the mass-spring element of the gauge. When an acceleration moves the mass against the spring, the armature is moved so as to cause an increased inductance in one coil and a decreased inductance in the other. This in turn causes an unbalance in the bridge measuring circuit which is in proportion to applied acceleration. Construction is such that only accelerations (or components) along the axis of concentricity of the gauge will cause the unbalanced condition in the mass-spring system required to move the armature.

The impedance accelerometer gauge is companion to the coupling unit shown in Fig. A.36 (see Sec. A.2.9). Figure A.37 shows how the two gauge coils are connected to form two active legs of the measuring bridge circuit with the secondary winding of the gauge supply transformer T1 acting as two fixed legs of the bridge.

Two different accelerometers were used, having maximum mechanical ratings of 20 and 100 g units, respectively, as indicated in Table A.9. These gauges are identical in appearance and construction except for the mass-spring components of the seismic elements. According to the manufacturer's data, the equivalent natural frequency, including mass effect of damping oil, of the 20 g unit is about 170 cps and of the 100 g unit is about 390 cps. Test records supplied by the manufacturer indicate that response time of the 20 g unit averages about 2.5 msec (to 95 per cent of final value) and of the 100 g unit averages about 1.1 msec (to 95 per cent of final value) with damping on both units running 0.6 to 0.7 of critical at 85°F.

A.3.6 Pressure Gauge, Impedance Type

Two impedance type pressure gauges (manufactured by Wiancko Engineering Company, Altadena, Calif.) used with the 24-channel tape recorder are shown in Fig. A.51. This type of gauge is identical magnetically and electrically with the accelerometer described in Sec. A.3.5 and was also used by Project 3.4. The coupling unit shown in Fig. A.36 is used interchangeably with pressure gauges and accelerometers.

The mechanical construction of the pressure gauge is different in that the magnetic armature, rather than being linked with a mass-spring system, is attached at the sealed end of a length of twisted Bourdon tube. The pressure being measured is introduced at the opposite end of the tube and tends to untwist it. In this manner the armature is moved, causing an increased inductance in one coil and a decreased inductance in the other. This, in turn, causes an unbalance in the measuring bridge circuit which is proportional to the applied pressure. Damping is accomplished acoustically by glass fiber threads through the length of the twisted Bourdon tube and mechanically by use of a silicone grease contained between surfaces of the armature and a fixed part of the gauge assembly.

Since the pressure being measured in the vehicles would normally appear on the outside

as well as the inside of the Bourdon tube and would result in zero pressure indication, it was necessary to seal the cover of the gauge with the small plug fitting shown beside the steel retaining ring in Fig. A.51. This sealed the chamber containing the Bourdon tube and thereby provided the necessary atmospheric reference pressure. The plug contains a small porous core of sintered bronze which permits changes of atmospheric pressure to be equalized in a period of 2 or 3 min.

Tests made on the pressure gauges at BRL indicate an average exponential response time of approximately 0.2 msec (to 95 per cent of final value) and a damping factor of about 0.67 of critical.

Figure A.52 shows the apparatus used for testing the pressure gauge with one of the gauges in place. In operation a piece of cellophane is inserted between two plates and clamped securely in place, forming a circular diaphragm of cellophane between a hole in the cover plate at the right and the opened end of the Bourdon tube of the gauge. Air is introduced in the small cavity between the gauge and cellophane through the copper tube at the left. When the pressure beneath the cellophane diaphragm reaches a predetermined value, a relay is energized; its armature carries a sharp stylus and ruptures the diaphragm suddenly. The response characteristic of the gauge is then observed on a cathode-ray oscilloscope as the pressure drops to atmospheric. Figure A.53 shows a typical record obtained in this manner. The gauge output bridge circuit is purposely left off-balance so that the signal does not go to zero when the diaphragm is broken. This provides a slightly clearer indication of gauge operation under the transient conditions. The test carrier frequency is 10,000 cps.

Figure A.54 is a combination schematic-pictorial diagram showing the complete test arrangement. The air pressure which goes to the pressure gauge and cellophane diaphragm also goes to the mercury manometer. When the mercury column rises to the point of contact of two wires, relay RY1 is energized, which in turn energizes relay RY2 to rupture the cellophane diaphragm. Contacts on relay RY2, together with a battery and resistance-capacitor network, provide a triggering pulse at the right moment for the cathode-ray oscilloscope. The coupling unit and the gauge make up the measuring bridge circuit. The audio generator and amplifier supply the bridge-circuit power, and the bridge output is connected to the balanced input circuit of the vertical amplifier of the oscilloscope.

A.3.7 Individual Amplifier-Recorder System

As a secondary means of recording air-temperature and wall-temperature data at positions 6311, 6312, and 6332, recorders manufactured by Sanborn Company, Cambridge, Mass., were used. Figure A.55 shows the d-c amplifier unit and the strip chart recorder with paper take-up as used with these systems. The recorder contains a D'Arsonval movement, and recording is done on temperature-sensitive paper with an electrically heated stylus. The stylus rides over a straight knife edge over which the recording paper travels. This arrangement provides a record having rectangular coordinates.

Since this recording system employs d-c amplifiers, it was desirable to have some means of checking for zero drift and sensitivity changes during recording in order to interpret better the final records. The calibration unit shown in Fig. A.56 was designed and built at BRL for this purpose. Two units are shown, one viewed from the rear with cover removed and the other from the front. In addition to the original requirements, the calibration unit was designed so that the outputs of two gauges would be recorded alternately. Figure A.57 shows a schematic wiring diagram of the calibration unit with remaining components of the amplifier recorder system indicated in block-diagram form. In operation, the −30-min signal turned on the entire system. A motor-operated cam in conjunction with three cam-operated microswitches and three relays provided the necessary programming. Resistor R_D is a voltage-dropping resistor to provide the proper voltage to the bridge circuit consisting of resistors R_1, R_2, and R_3, the three fixed legs of the bridge and the two temperature gauges acting alternately as the fourth leg. Resistor R_C is a calibration resistor which is switched into the bridge circuit for amplifier sensitivity check. Relay B periodically shorts the amplifier input to provide the zero drift check.

The resulting record program is made up of a $\frac{1}{2}$-sec zero step followed by a 2-sec step of gauge No. 1, followed by a $\frac{1}{2}$-sec calibration

step, followed by a 2-sec step of gauge No. 2; and the cycle starts over. Gauges were carefully calibrated with the amplifier recorder system before the test.

A.3.8 Air-temperature Gauge

Figure A.59 shows a completed resistance-wire air-temperature gauge as used with the 24-channel tape recorder. Air temperature gauges were made by Project 6.3 personnel at BRL. The air-temperature gauges used with the amplifier-recorder systems (Sec. A.3.7) were similar except that the 300-ohm precision resistors were not required. Shown beside the completed gauge in Fig. A.59 is the double-element gauge assembly from a similar gauge. The 300-ohm length of resistance wire is held in place on the plastic half-cylinder pieces with cement. End ports of the gauge contain baffle pieces to protect the delicate resistance elements. Figure A.58 is a sketch showing construction details of the gauge, as well as technical data on the alloy resistance wire.

A.3.9 Wall-temperature Gauge

Figure A.61 shows two of the resistance-wire wall-temperature gauges (also made by Project 6.3 personnel) as used with the 24-channel tape recorder, and the d-c amplifier recorders. The same alloy resistance wire is used with these gauges as with the air-temperature gauges except that in this case the wire grid is cemented between paper. The active element was held in contact with the vehicle wall by clamping the gauge down by use of studs welded to the vehicle wall. Figure A.60 is a sketch of the wall-temperature gauge showing mechanical details.

A.3.10 Pressure Gauges, Foil-rupture

The foil-rupture gauges used in the five vehicles at the nearest two ranges were obtained from those originally built and used for Operation Sandstone in 1948.[1] Two modifications were required on the original foil gauges before they could be used in the vehicles. First, the size was cut down by removing a section from the center of the case and rewelding it. Second, closed tubes had to be welded behind each gauge hole to make each diaphragm an independent gauge. The latter modification was required because of the relatively slow pressure-rise times expected inside the closed vehicle. The sketch in Fig. A.62 shows the mechanical details of the modified foil-rupture gauge and a table showing gauge hole numbers and diameters. Figure A.63 shows one of the foil-rupture gauges ready for assembly (with 0.001-in.-thick aluminum foil in foreground) after modifications. Figure A.64 shows the same gauge assembled with 0.001-in.-thick aluminum foil in place. In use the foil was installed the day before the shot and then carefully sprayed with silicone oil to prevent its rusting in the humid atmosphere.

It may be noted that the gauge shown in Figs. A.63 and A.64 contains about two dozen extra tapped holes in the front plate. These were used in connection with the calibration tests described in the following paragraphs.

A.3.11 Calibration of Foil-rupture Gauge

The foil meters were originally used for peak pressure measurements of shock waves, and, since the inside vehicle pressures involved relatively longer rise times, the calibration data given in the Sandstone Report[1] were of little direct value. Figure A.65 is a combination pictorial-schematic sketch showing the test arrangement used in obtaining the applicable calibration data.

A calibration plate was made to cover the particular gauge hole being tested. The plate was fitted with a suitable pressure inlet and one of the impedance type pressure gauges described in Sec. A.3.6. Operation of the gauge circuit including coupling unit, audio generator, and input to cathode-ray oscilloscope is similar to that described for Fig. A.54 in Sec. A.3.6. In operation of the test arrangement shown in Fig. A.65, closing the firing switch triggers the oscilloscope single sweep and at the same time opens the solenoid valve to apply pressure to the foil-rupture gauge section under test. The resulting trace on the oscilloscope shows the 2000-cps carrier amplitude increase as pressure builds up on the 0.001-in. aluminum foil. At rupture the vertical trace drops to a line for the remainder of the sweep. The vertical deflection on the oscilloscope was calibrated statically (in pounds per square inch) against a high-accuracy Bourdon type calibration gauge. Sweep time of horizontal deflection was calibrated against known frequency standards. The

oscilloscope trace was photographed, and values of rupture pressure and rise time were obtained by scaling. Variation of rise time was obtained by adjustment of the pressure regulator. Pressure rise characteristics were approximately linear. Approximately 25 records were made for each of gauge hole Nos. 1, 2, 3, and 8.

Curve No. 1 in Fig. A.66 shows the resulting calibration. The four points represent an average of the data taken for each of the four gauge holes tested. In the case of gauge holes 1, 2, and 3 it was found that rupture pressures remained constant as indicated for rise times (to rupture) of 0.05 sec and longer (to near static conditions). Physical constants of the test arrangement prevented rise times shorter than 0.1 sec for the No. 8 gauge hole, but rupture pressure was found to be similarly constant for longer times. Since pressure rise time within the closed vehicles was longer than the 0.1 sec, it was not necessary to carry the tests further.

Curves 2 and 3 in Fig. A.66 are reproduced from a Sandstone Report[2] and represent two sets of calibration data obtained for side-on shock waves. The Sandstone Report notes that theoretically the curves should be a straight line with a slope of 45° when rupture pressure versus reciprocal of hole diameter is plotted on logarithmic scales. It is interesting to note that the BRL static-dynamic curve obtained as described produced a slope of almost exactly 45°. The same lot of 0.001-in. aluminum foil was used for all three curves in Fig. A.66, as well as for the actual test within the vehicles.

A.3.12 Temperature-sensitive Paint and Capsules

A temperature-sensitive paint was procured from Tempil Corp., New York, for use as rough peak temperature measurements on wall surfaces. The paints were in a wide variety of colors to represent different temperature levels. When the critical temperature was reached, the surface texture of the paint underwent a change. Although the paint seemed to work under laboratory conditions, it did not function properly in the field.

Temperature-sensitive capsules obtained from the same source were probably somewhat more reliable. However, the problem of applying them to the temperature-measurement problems was rather difficult, and the meager data obtained are of questionable value.

A.3.13 Scratch Gauges

Figure A.67 is a sketch showing mechanical details of a scratch gauge as designed and constructed at BRL for recording motion of the gun turret during the shot. It was determined before the shot, however, that such records would, in this case, have little or no significance. The drawing is reproduced for record purposes.

A.3.14 Recording Instruments

The recording instruments were similar to the recorders of the d-c amplifier-recorder systems described in Sec. A.3.7. One of these recorders was provided for each of the 24-channel tape recorders. Their purpose was to monitor the battery voltage available for the 24-channel tape recorders and to provide a record of the operating history (on-off time) of the 24-channel recorder from the voltage fluctuations. Under certain conditions of low battery voltage the recorders were known to be somewhat unreliable. The voltmeter records made it possible to interpret 24-channel records with a higher degree of certainty.

REFERENCES

1. Sandstone Report, Annex 5, Vol. 21, "Blast Measurement of Peak Pressure," Chaps. 5.1 and 5.2.
2. Sandstone Report, Annex 5, Vol. 21, "Blast Measurement of Peak Pressure," p 22.

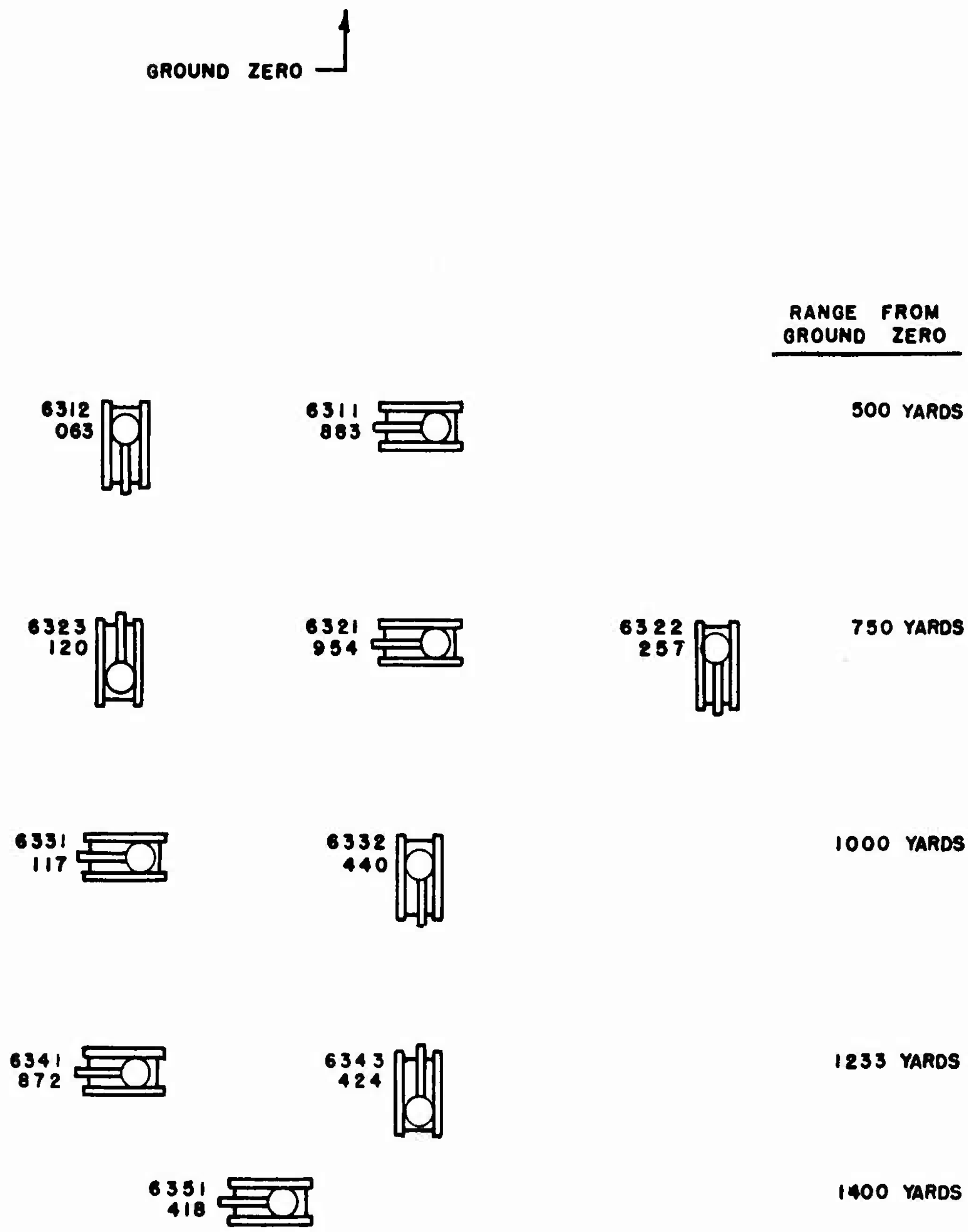


Fig. A.1 Field Arrangement of Test Vehicles Showing Range from Ground Zero, Relative Orientation, and Numerical Identification of Each

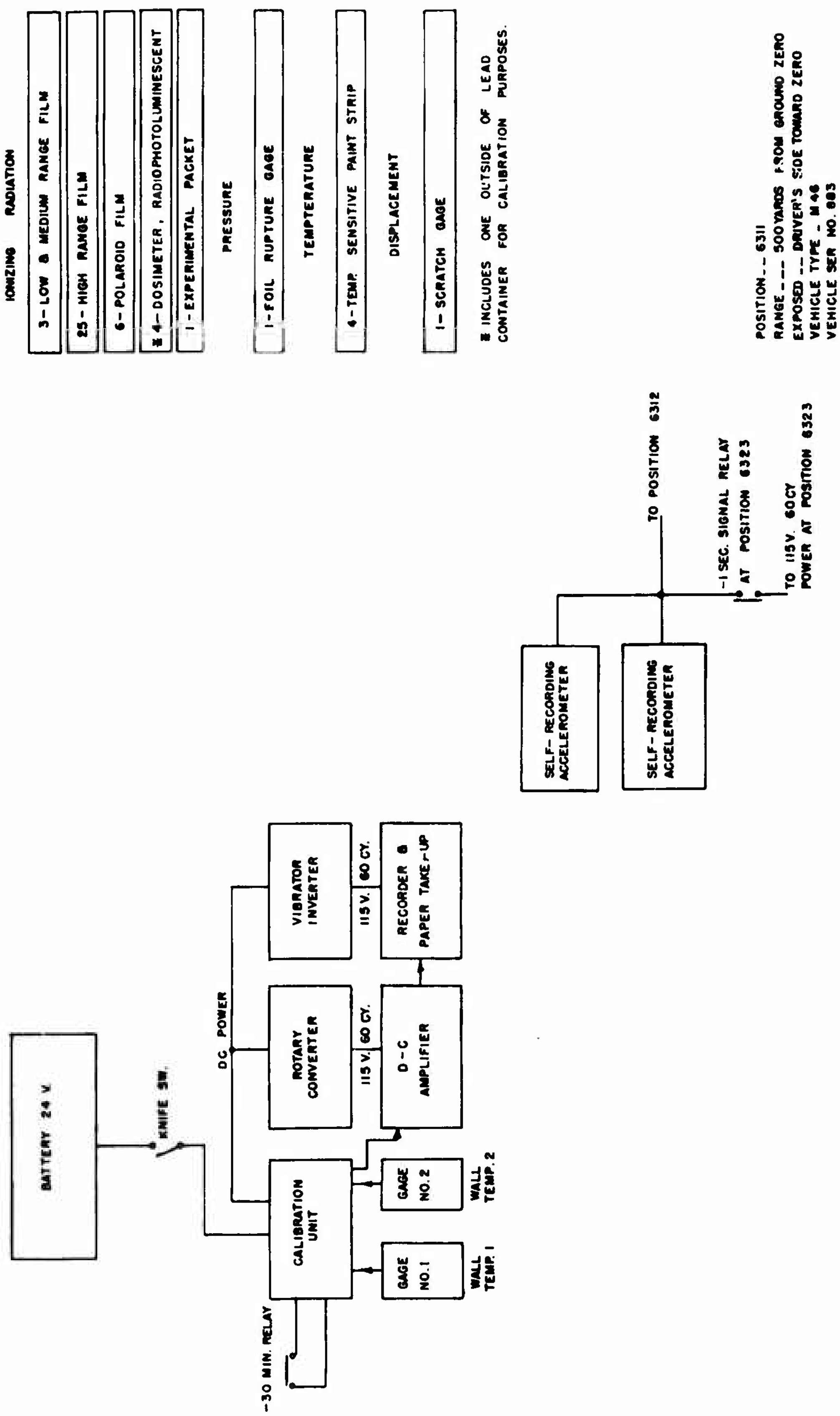


Fig. A.2 Instrumentation Plan for Position 6311

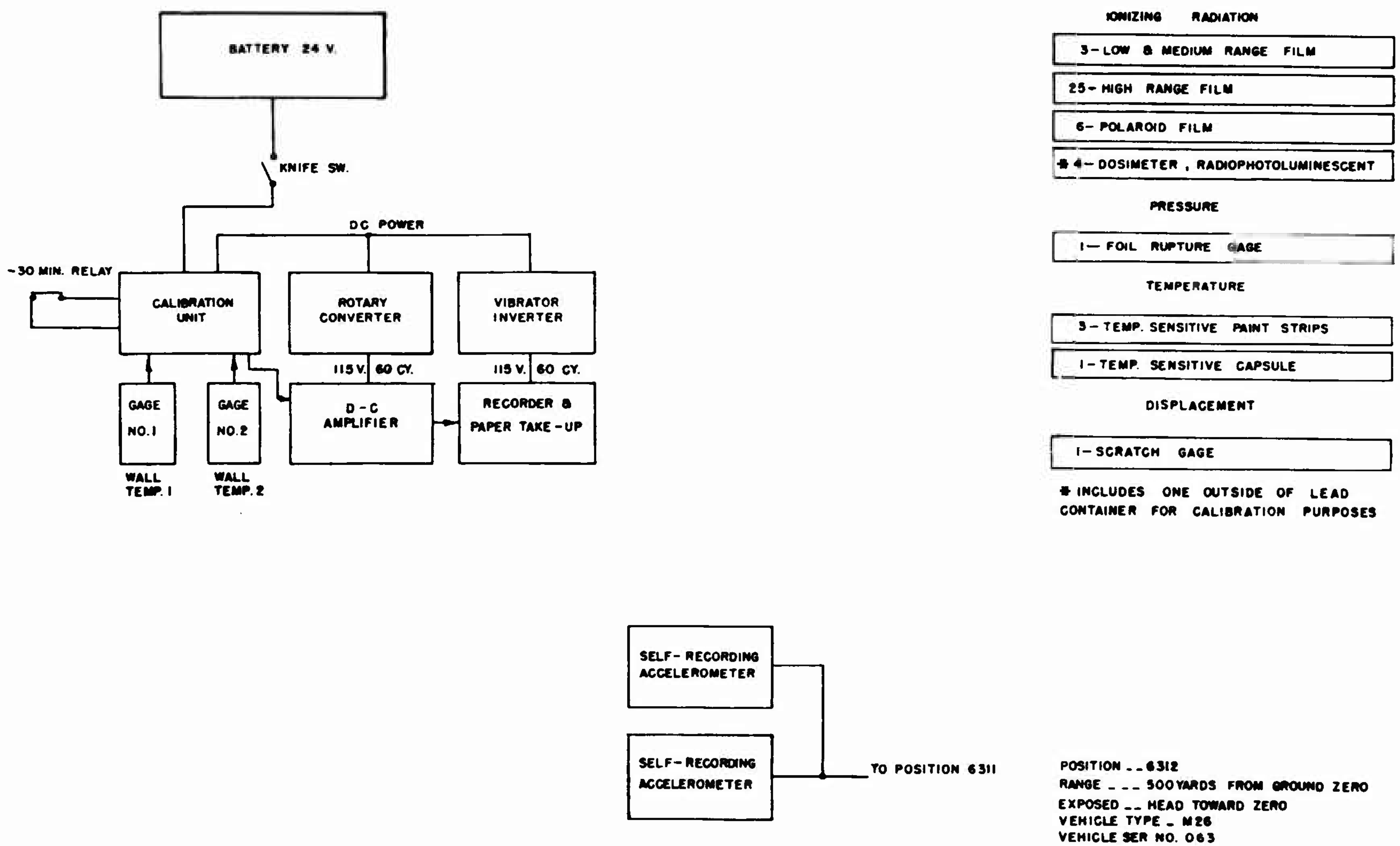


Fig. A.3 Instrumentation Plan for Position 6312

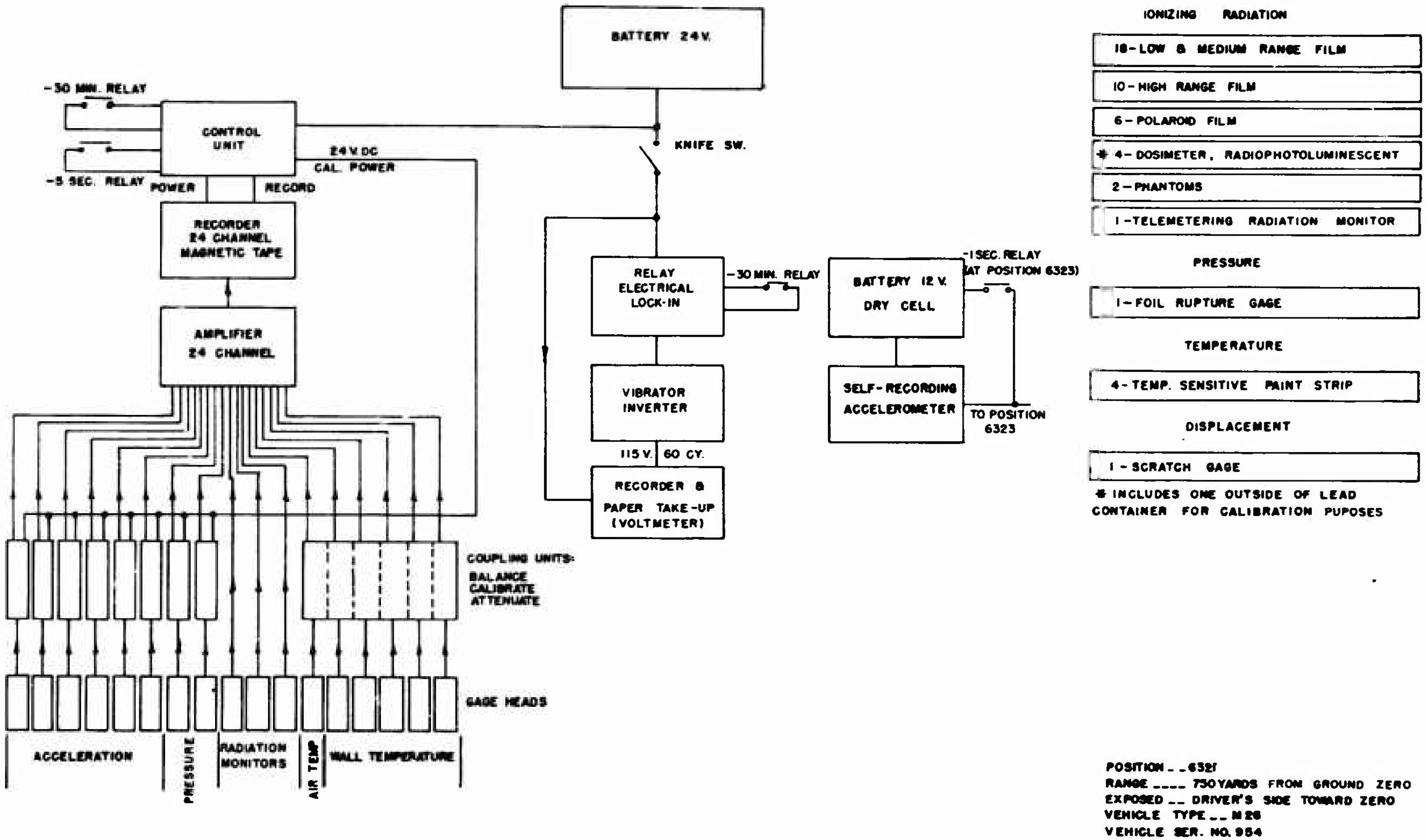
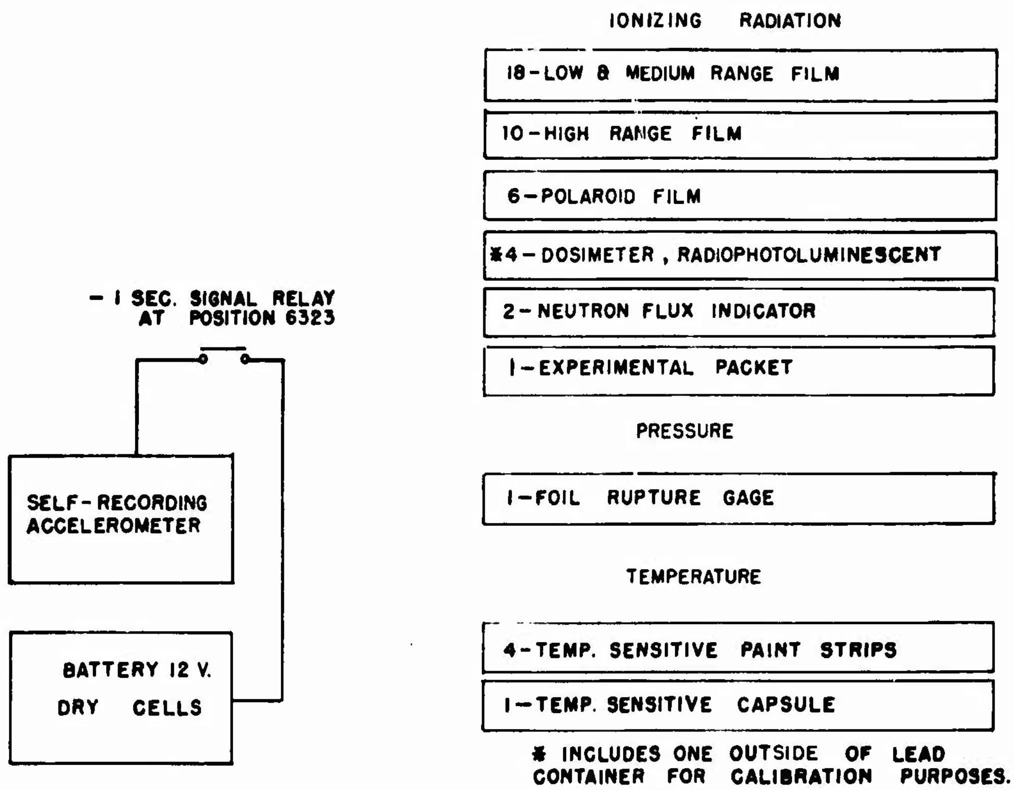


Fig. A 4 Instrumentation Plan for Position 6321



POSITION -- 6322
RANGE --- 750 YARDS FROM GROUND ZERO
EXPOSED -- HEAD TOWARD ZERO
VEHICLE TYPE -- M26
VEHICLE SER. NO. 257

Fig. A.5 Instrumentation Plan for Position 6322

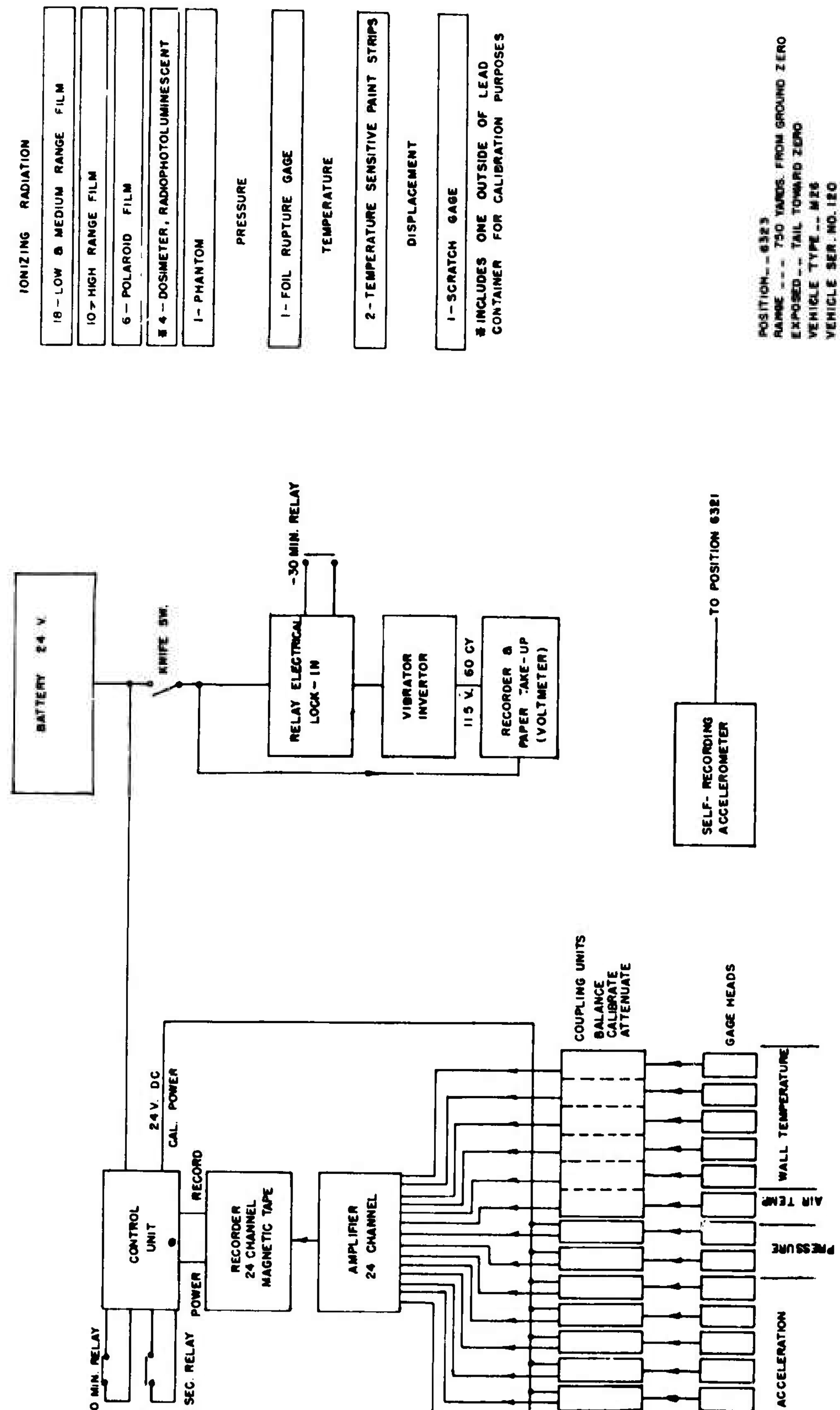


Fig. A.6 Instrumentation Plan for Position 6323

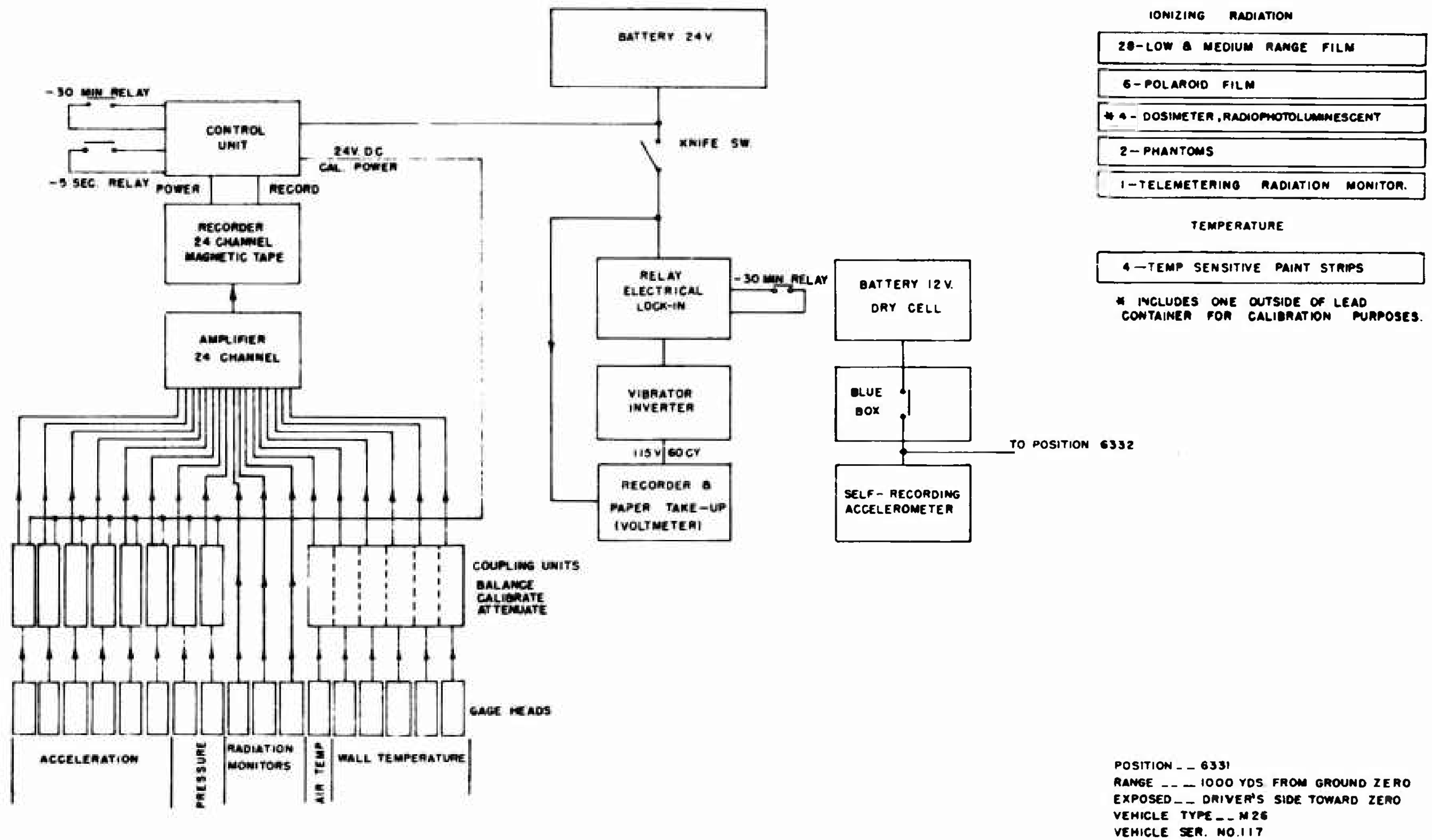


Fig. A.7 Instrumentation Plan for Position 6331

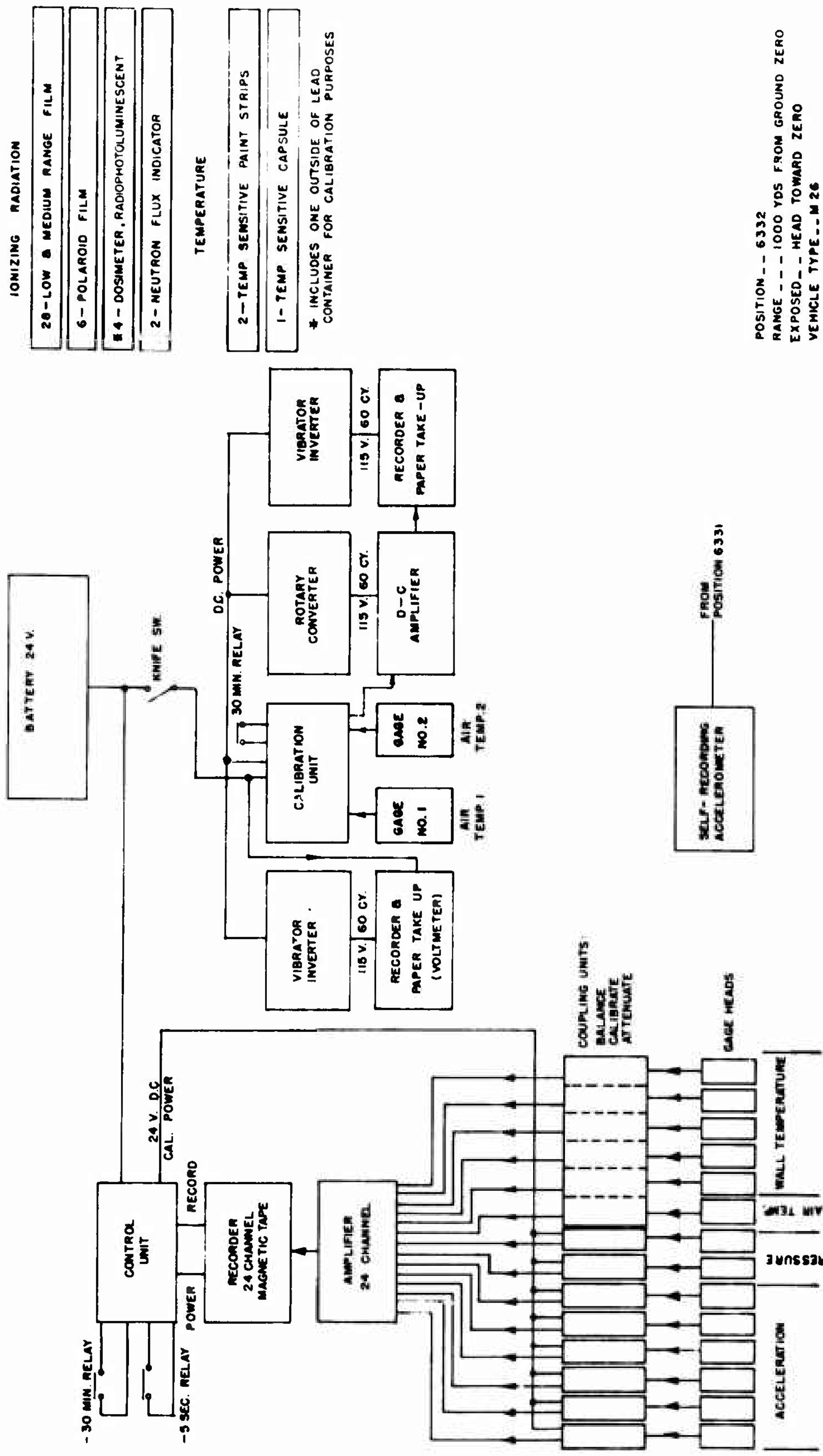


Fig. A.8 Instrumentation Plan for Position 6332

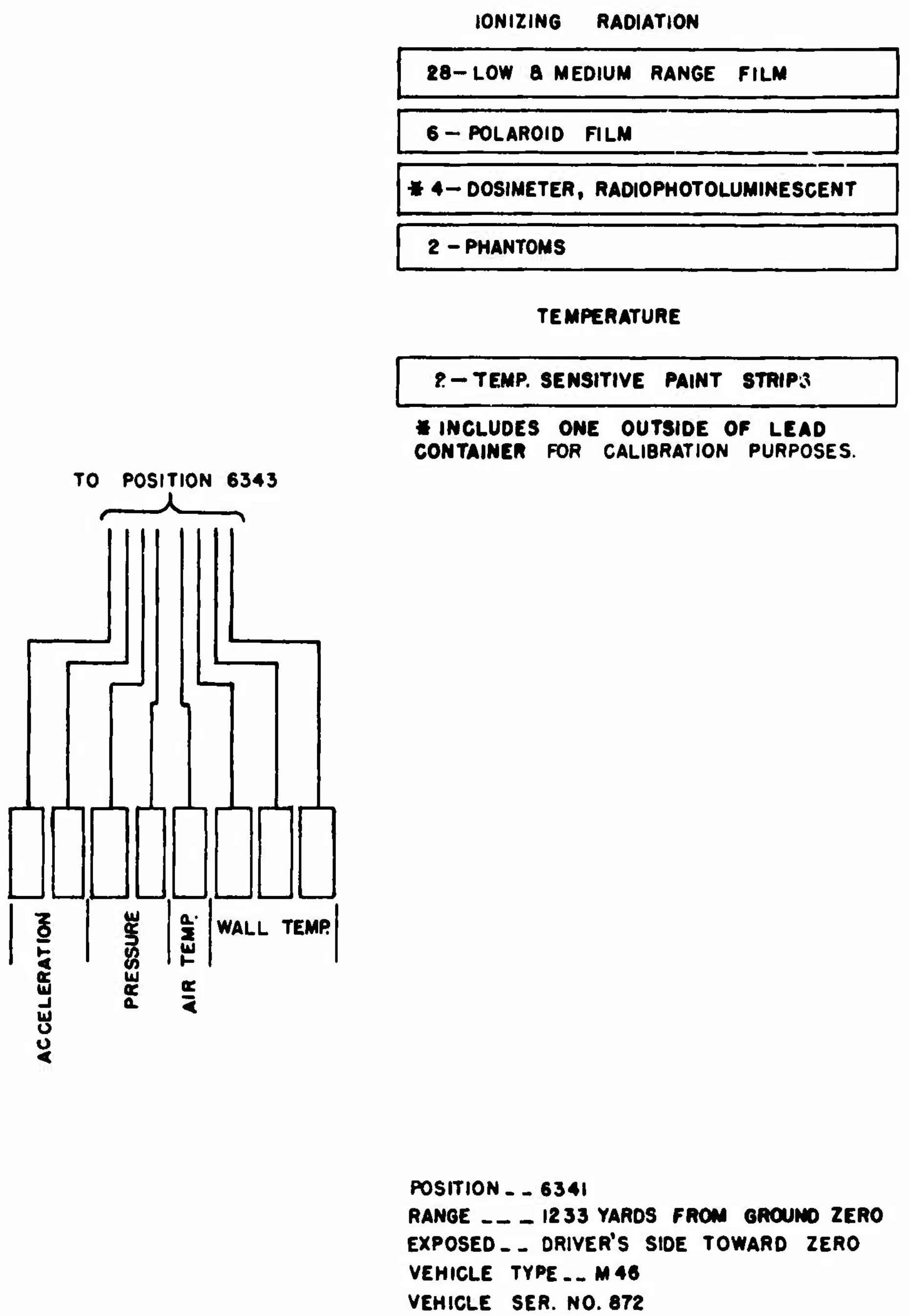


Fig. A.9 Instrumentation Plan for Position 6341

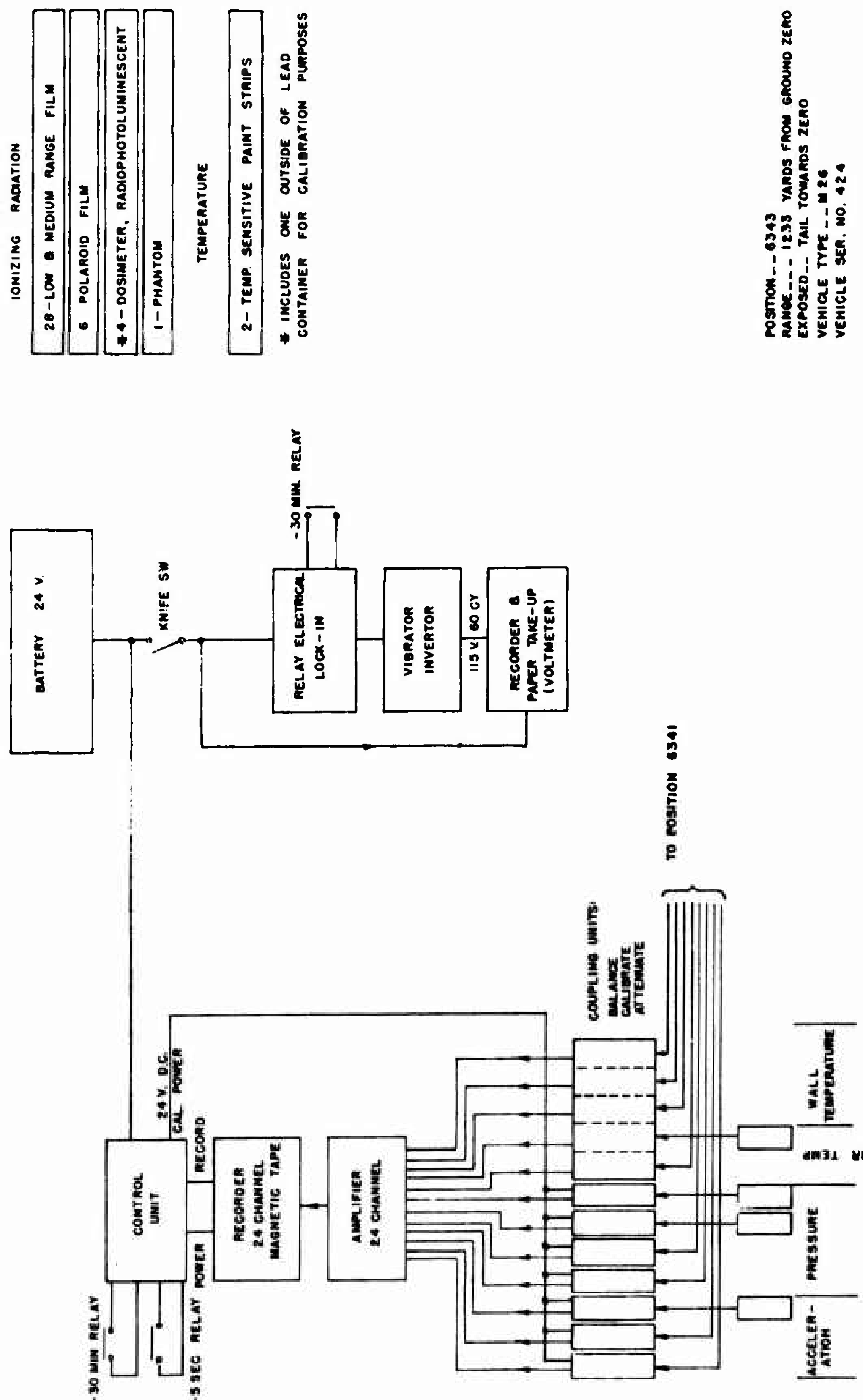


Fig. A.10 Instrumentation Plan for Position 6343

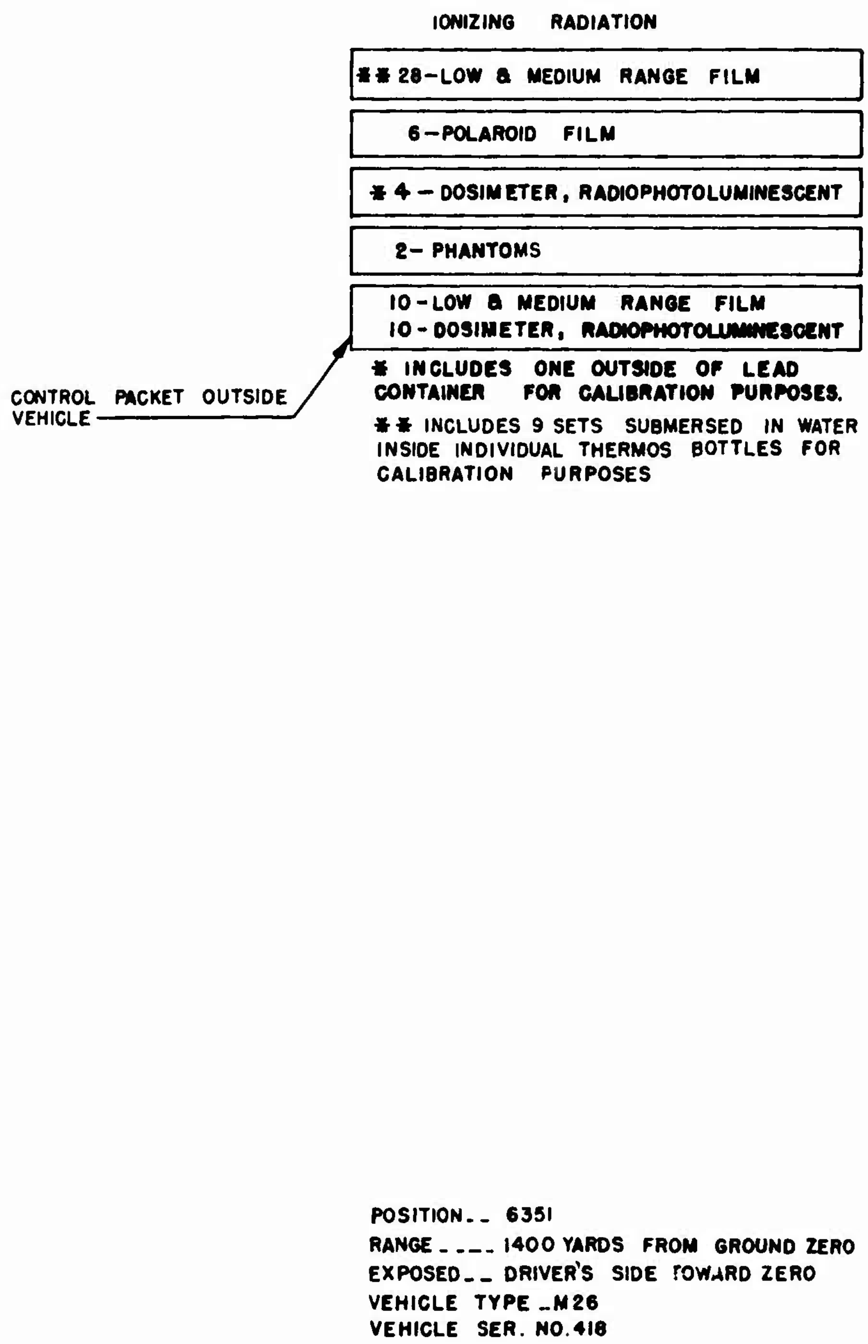


Fig. A.11 Instrumentation Plan for Position 6351

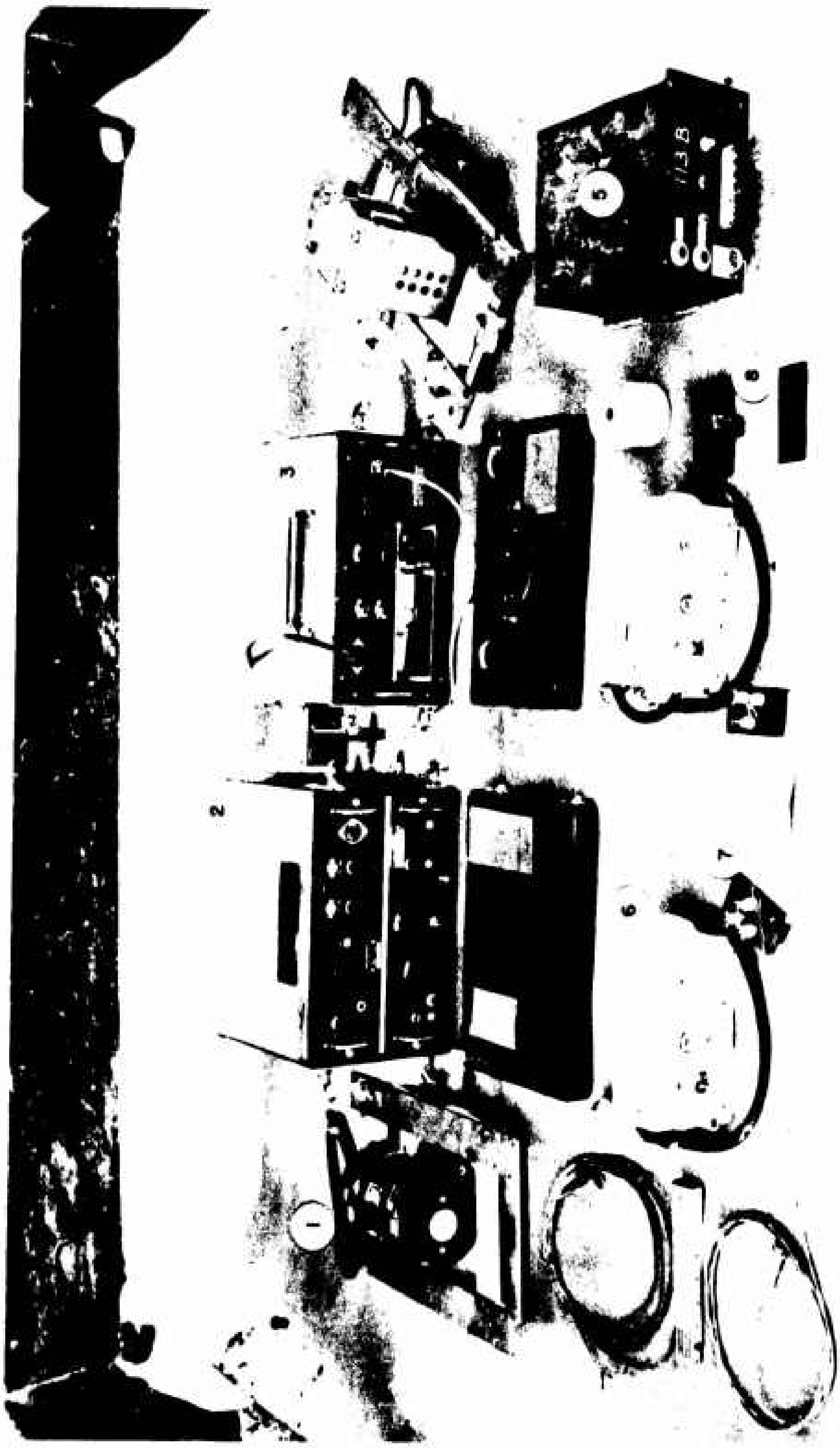


Fig. A.12 Partial Instrumentation Layout for Position 6311. 1, Rotary converter. 2, D-c amplifier. 3, Recorder and paper take-up. 4, Vibrator inverter. 5, Calibration unit. 6, Self-recording accelerometer (2). 7, Wall-temperature gauge (2). 8, Scratch gauge and plate, recording paper, cables, etc.

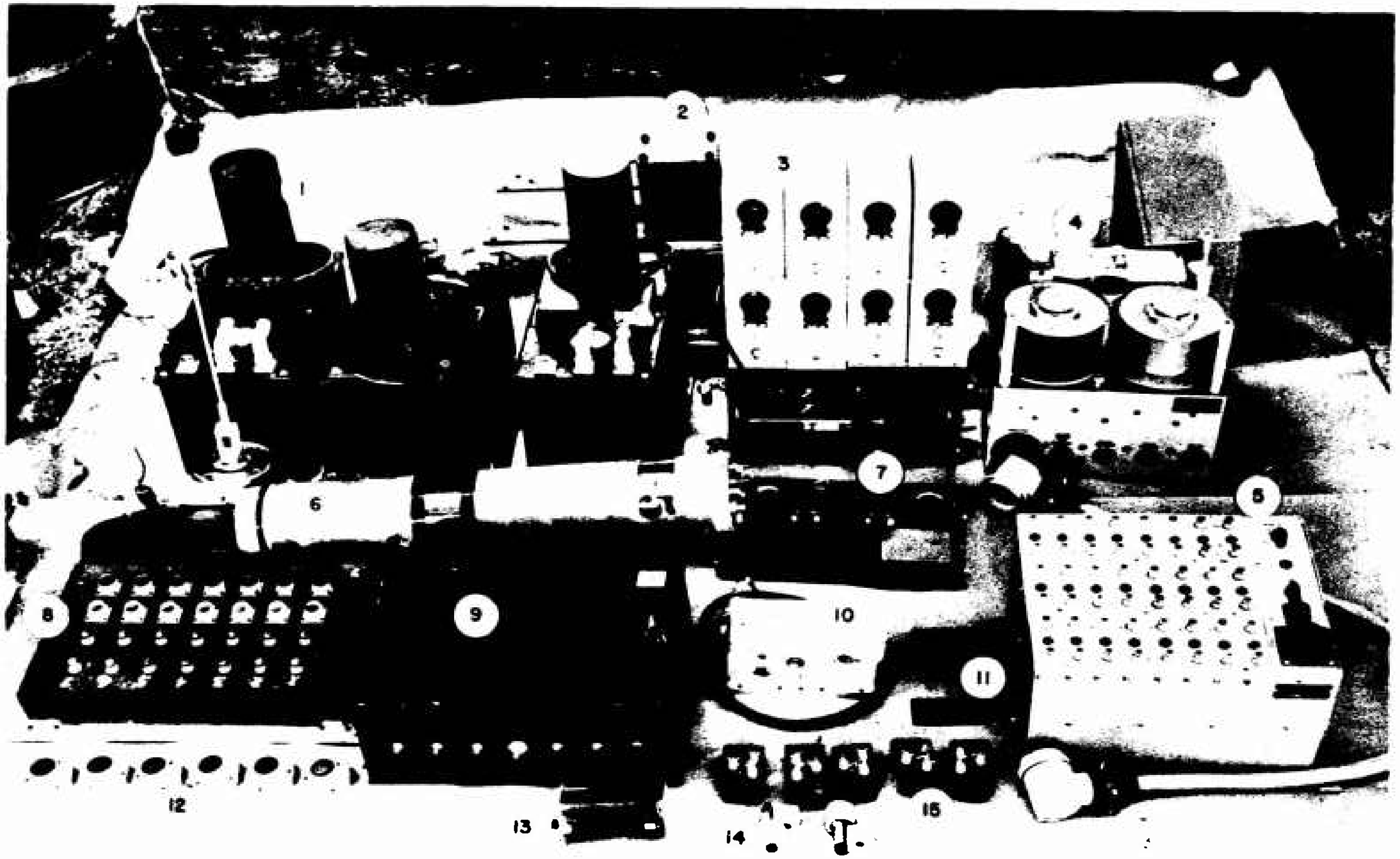


Fig. A.13 Partial Instrumentation Layout for Position 6321. 1, Radiation monitor gauge (3). 2, Vibrator inverter. 3, Coupling unit for impedance gauges (8). 4, Recorder, 24-channel magnetic tape. 5, Amplifier, 24-channel. 6, Telemetering radiation monitor with antenna. 7, Recorder and paper take-up. 8, Coupling unit, 7-channel, for resistance gauges. 9, Control unit. 10, Self-recording accelerometer. 11, Scratch gauge. 14, Pressure gauge and mounting block (2). 15, Wall-temperature gauge, cables, covers, etc. (5).

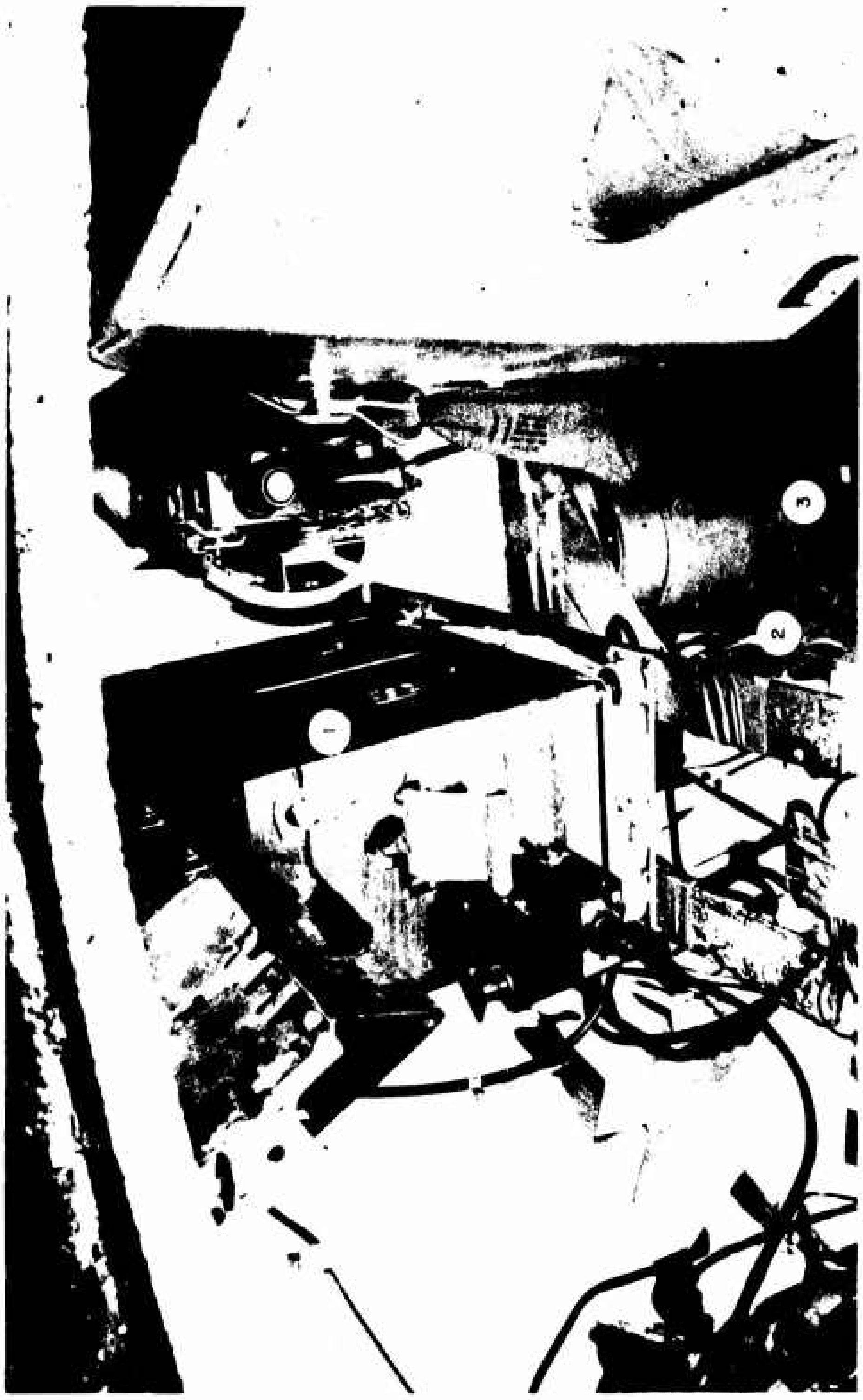


Fig. A.14 Typical Installation of Recording Voltmeter at Position 6321. 1, Recorder and paper take-up. 2, Air-temperature gauge taped with foam rubber beneath support arm. 3, Radiation monitor and size 11 sock as film badge container tied on gun breech shield.

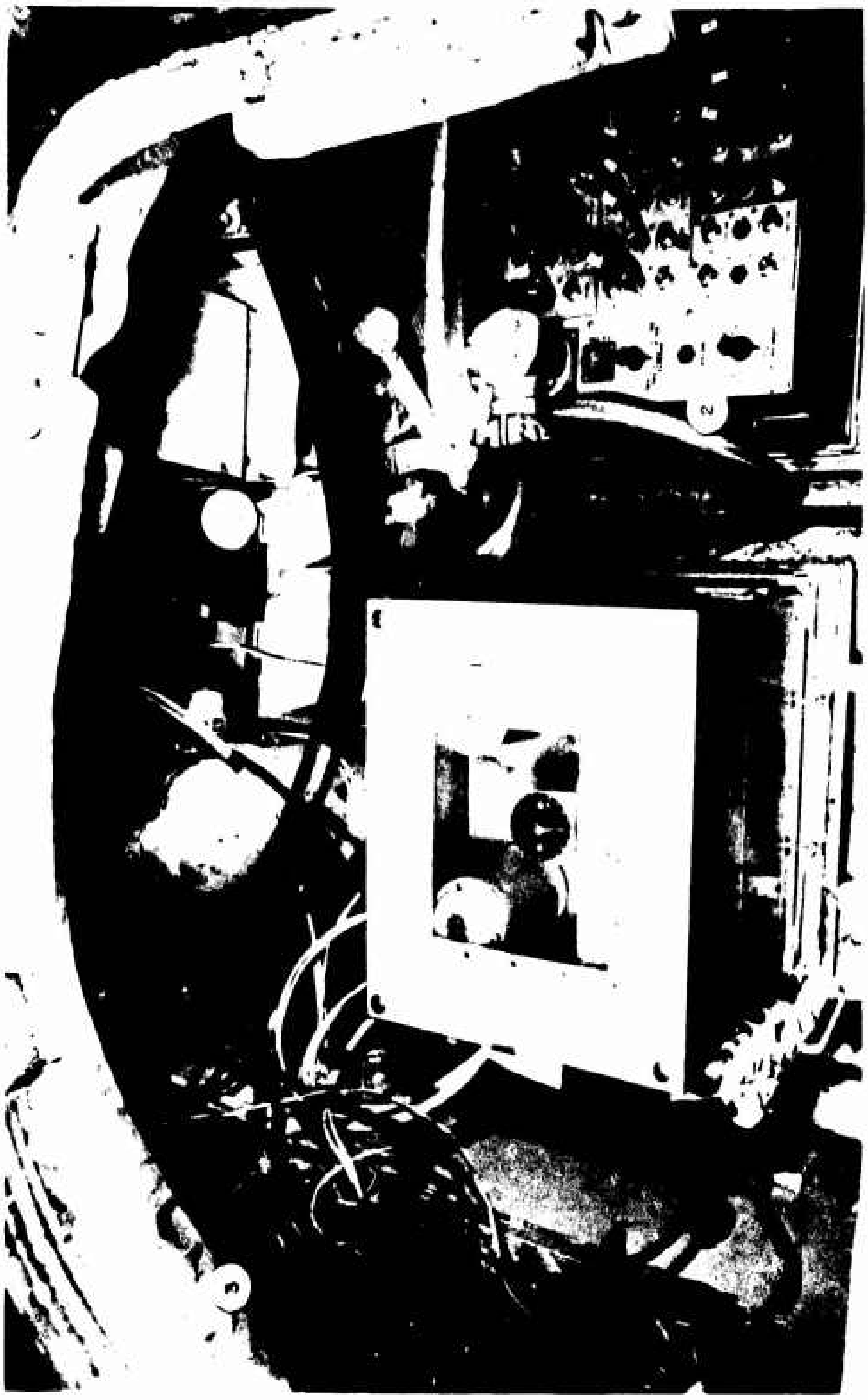


Fig. A.15 Typical Installation of Equipment. 1, Recorder, 24-channel magnetic tape. 2, Amplifier, 24-channel. 3, Control unit. (As seen looking into vehicle through assistant driver's hatch at position 6321.)

Fig. A.16 Typical Installation of Equipment. 1, 24-channel tape recorder. 2, Control unit. 3, Radiation monitor. (As seen looking into vehicle through assistant driver's hatch at position 6321.)

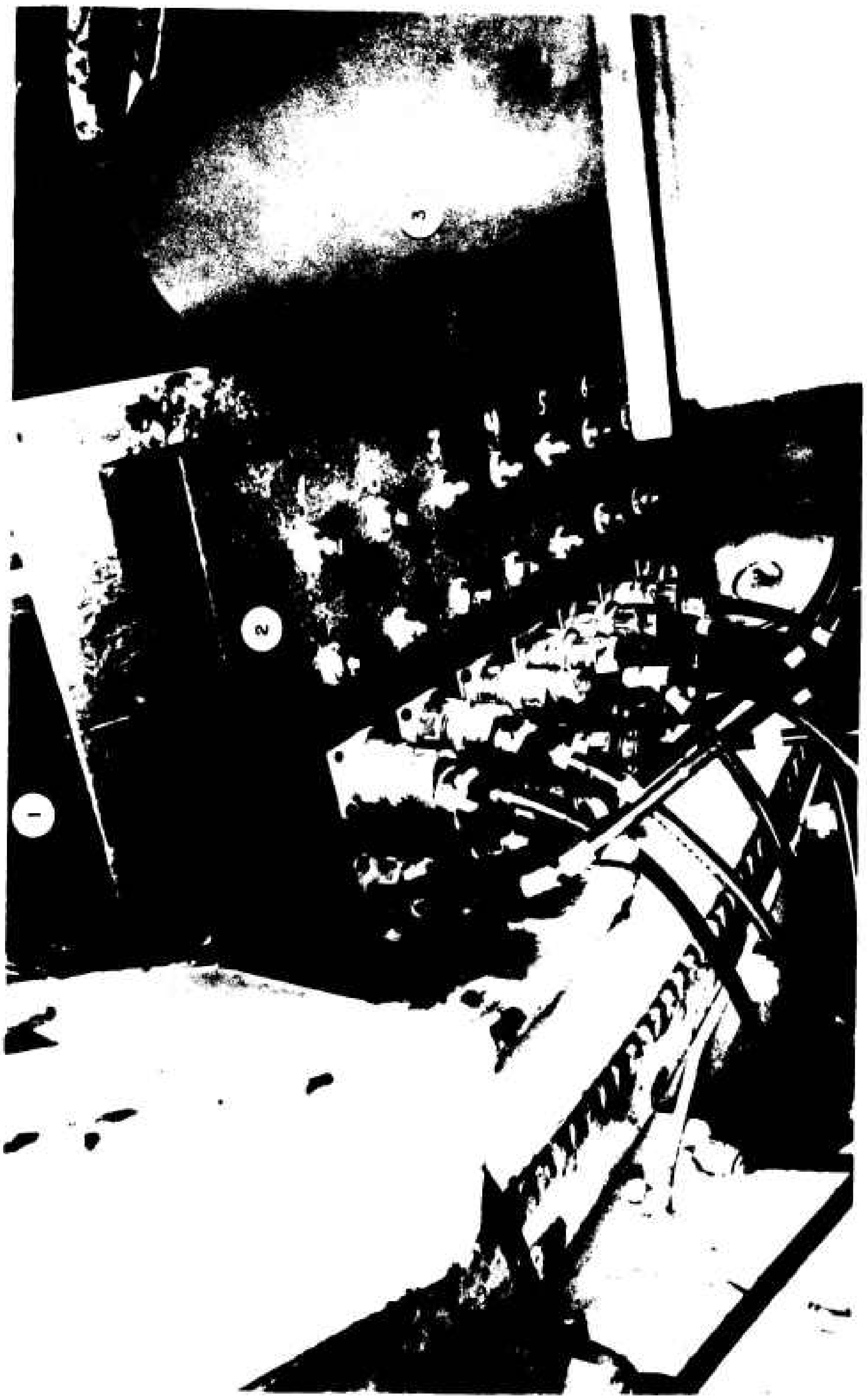


Fig. A.17 Typical Installation of Equipment. 1, Portion of foil-rupture gauge mounted directly behind gun breech. 2, 7-channel resistance gauge balancing unit. 3, Radiation monitor. (As seen from floor of vehicle looking up toward assistant gunner's hatch at position 6321.)

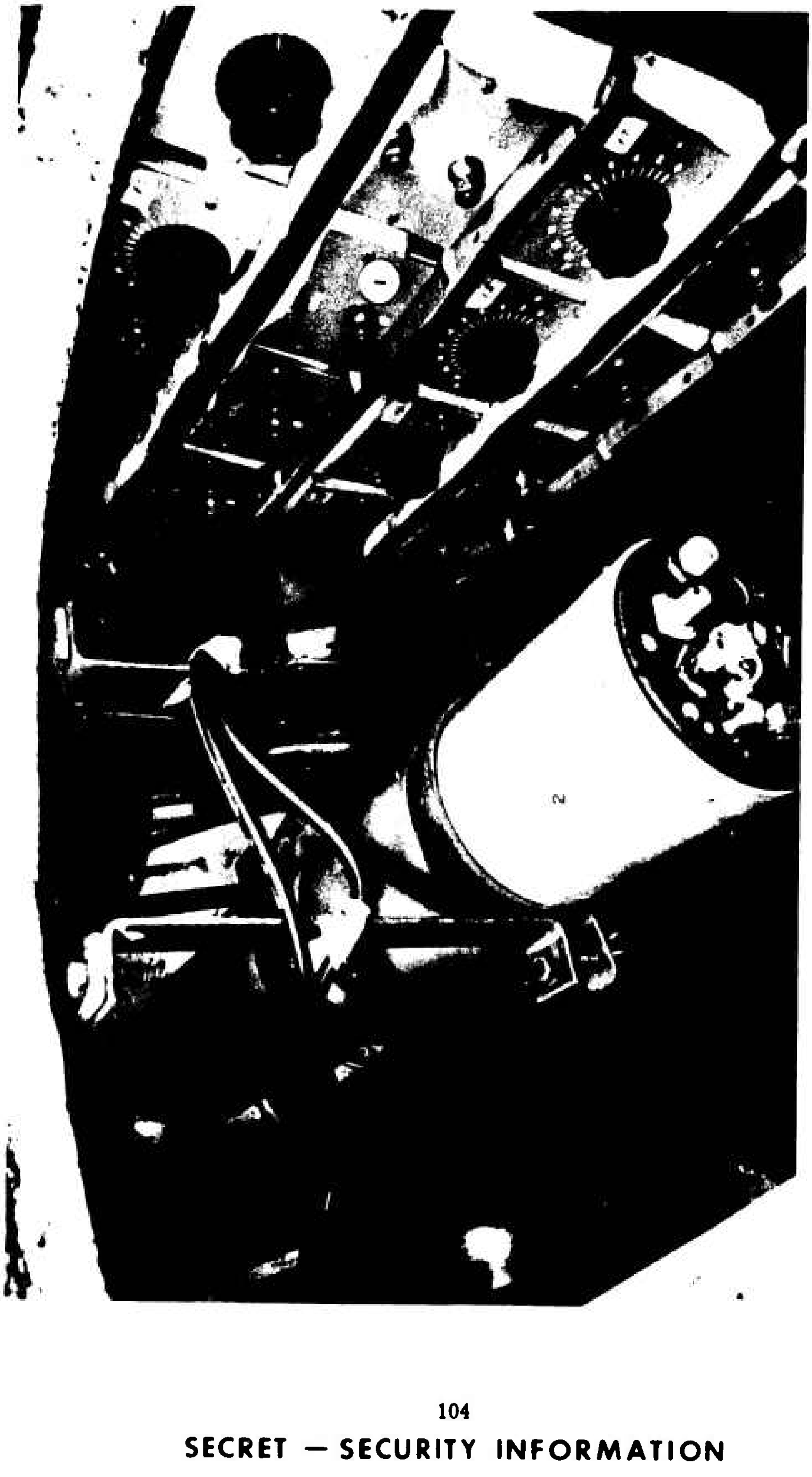


Fig. A.18 Typical Installation of Equipment. 1, Rack containing eight individual coupling units for impedance type accelerometers and pressure gauges. 2, Telemetering radiation monitor. (As seen through assistant gunner's hatch at position 6321.)

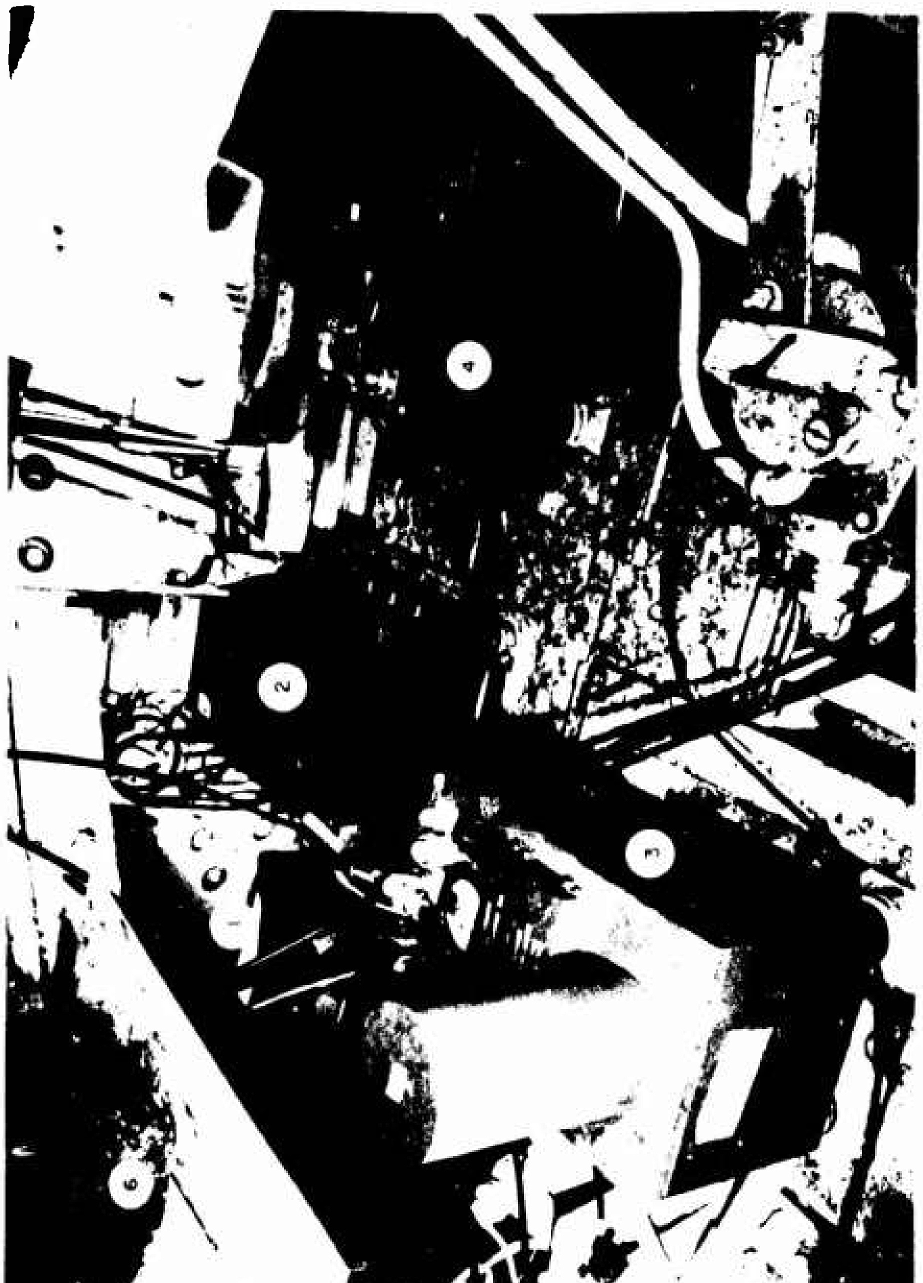
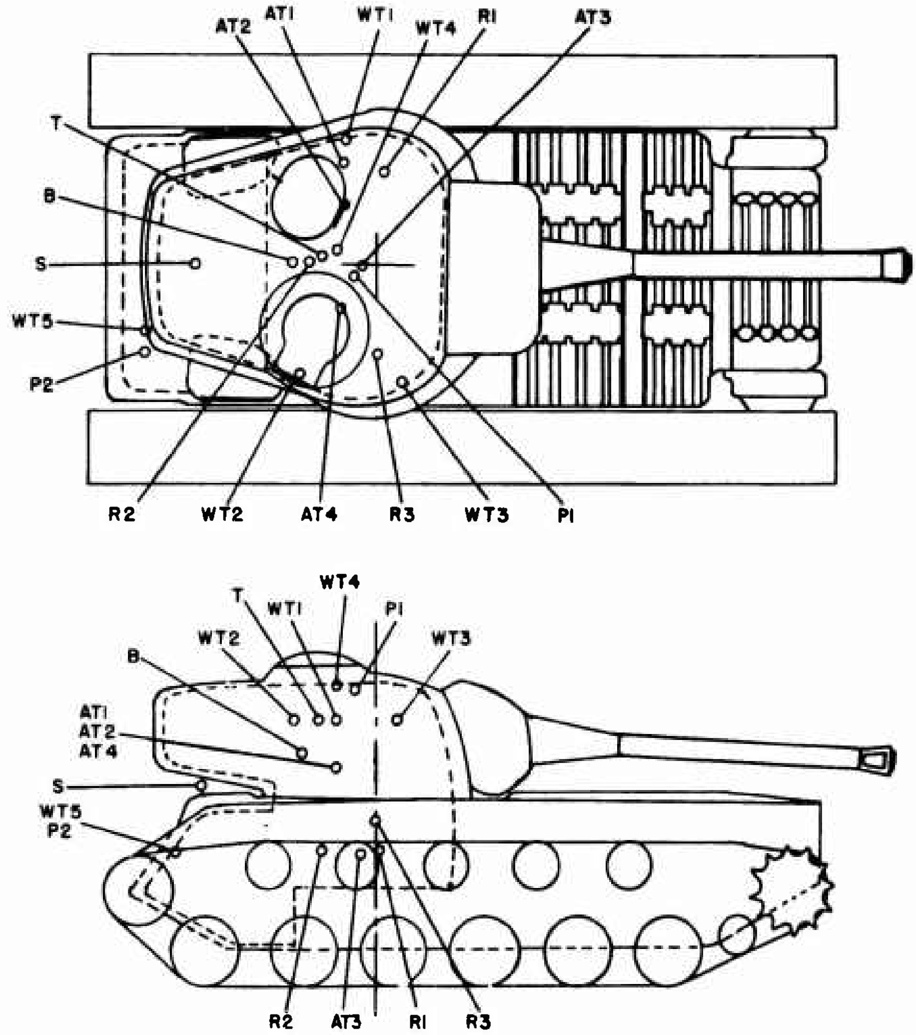


Fig. A.19 Typical Installation of Equipment. 1, 24-channel tape recorder. 2, Control unit. 3, Radiation monitor. 4, Radiation monitor. 5, 7-channel resistance gauge balancing unit. 6, Foil-rupture gauge. (As seen from commander's seat at position 6321.)



P__ PRESSURE GAGE, AIR
B__ BLAST GAGE, FOIL
WT_ TEMPERATURE GAGE, WALL
AT_ TEMPERATURE GAGE, AIR
R__ RADIATION, (IONIZING) MONITOR
T__ TELEMETERING RADIATION, (IONIZING) MONITOR
S__ SCRATCH GAGE

Fig. A.20 Vehicle Gauge Location Diagram Showing All Gauges except Accelerometers and Radiation Dosimeters

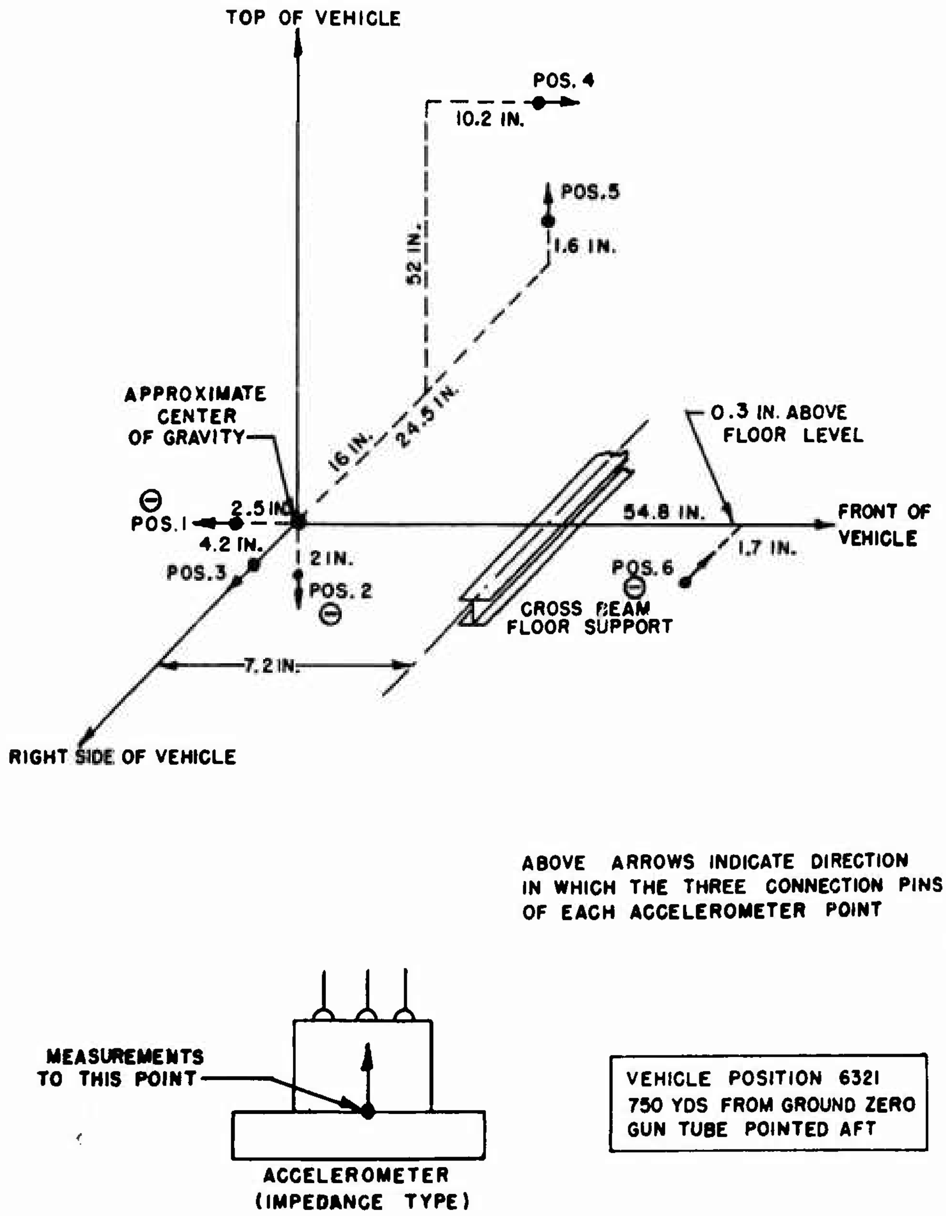


Fig. A.21 Accelerometer, Impedance Type, Location Diagram for Position 6321

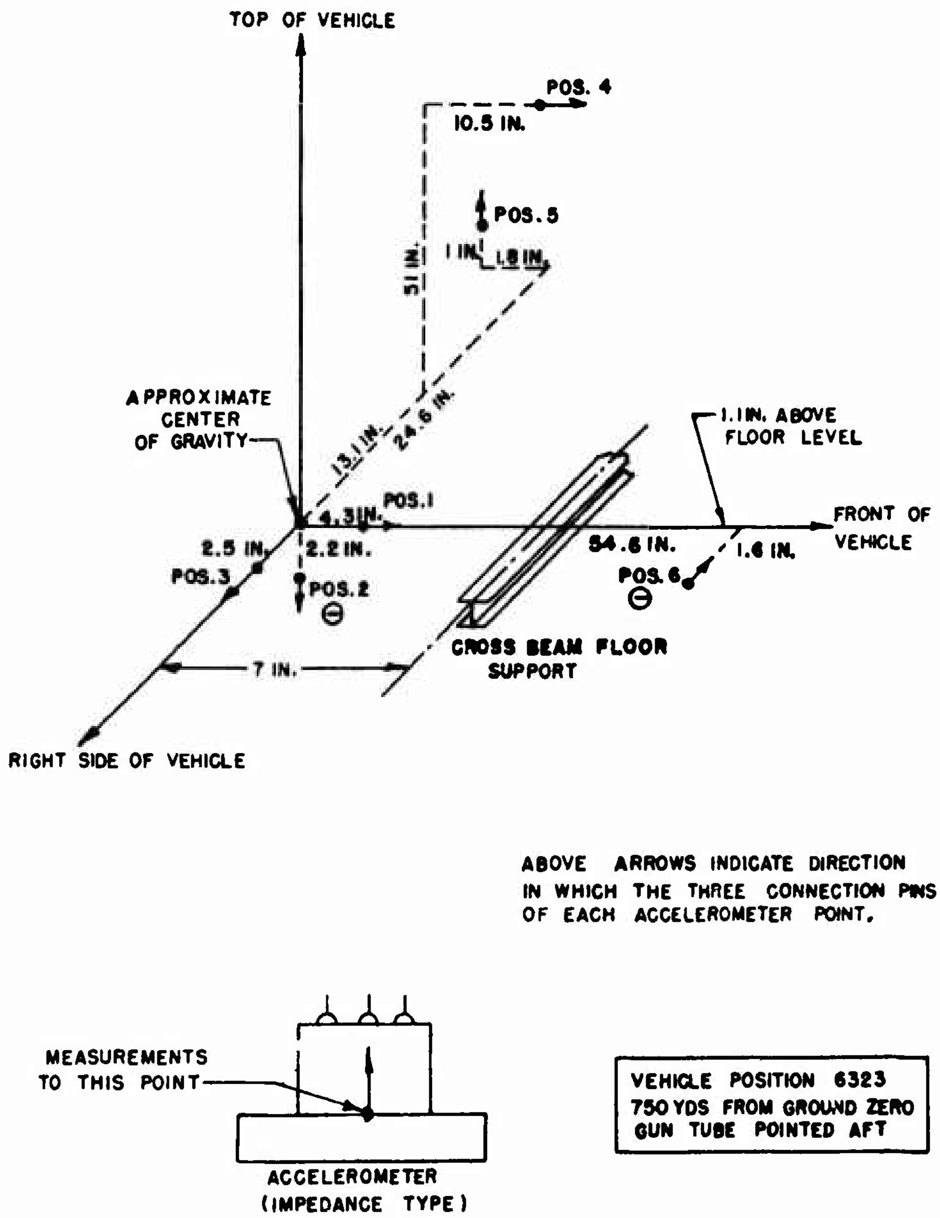


Fig. A.22 Accelerometer, Impedance Type, Location Diagram for Position 6323

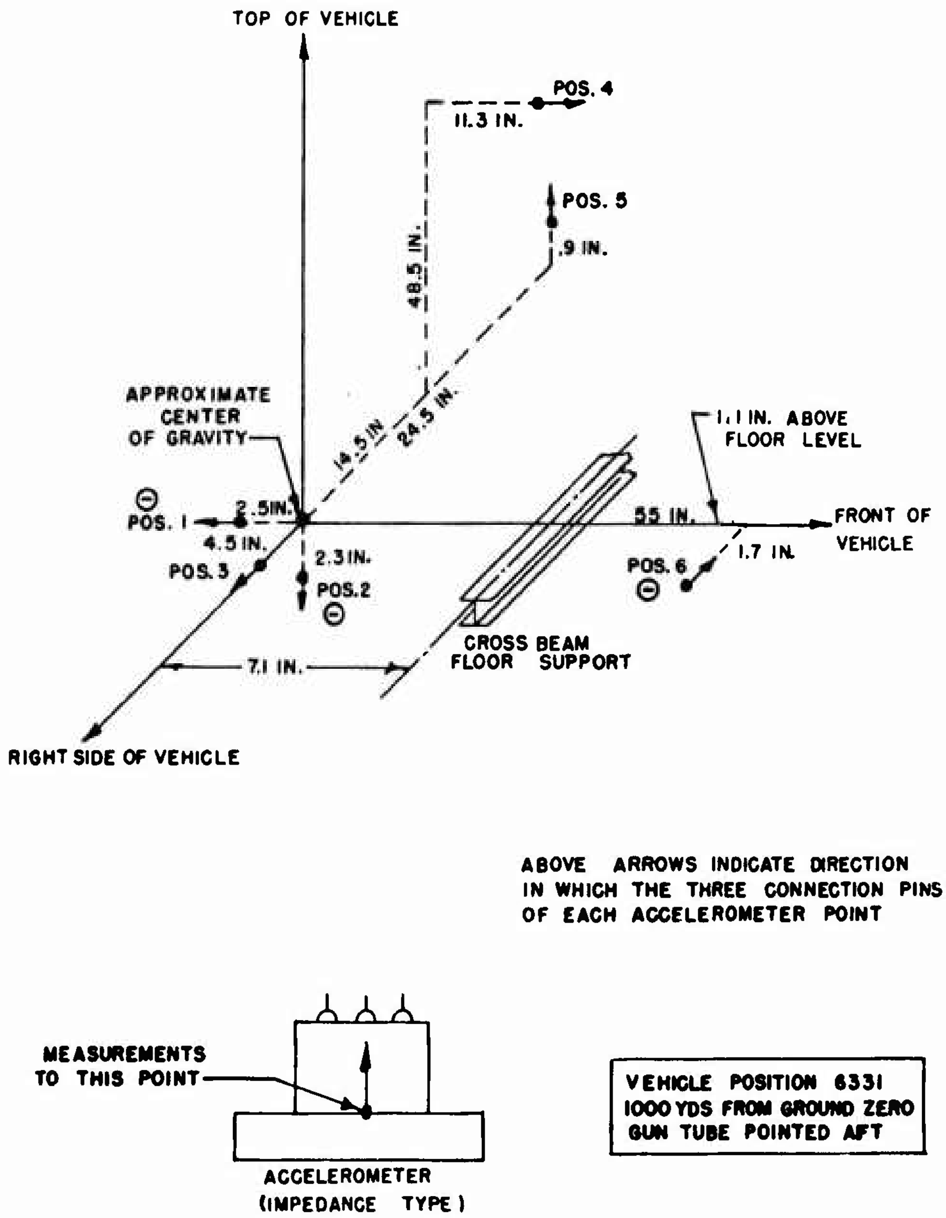


Fig. A.23 Accelerometer, Impedance Type, Location Diagram for Position 6331

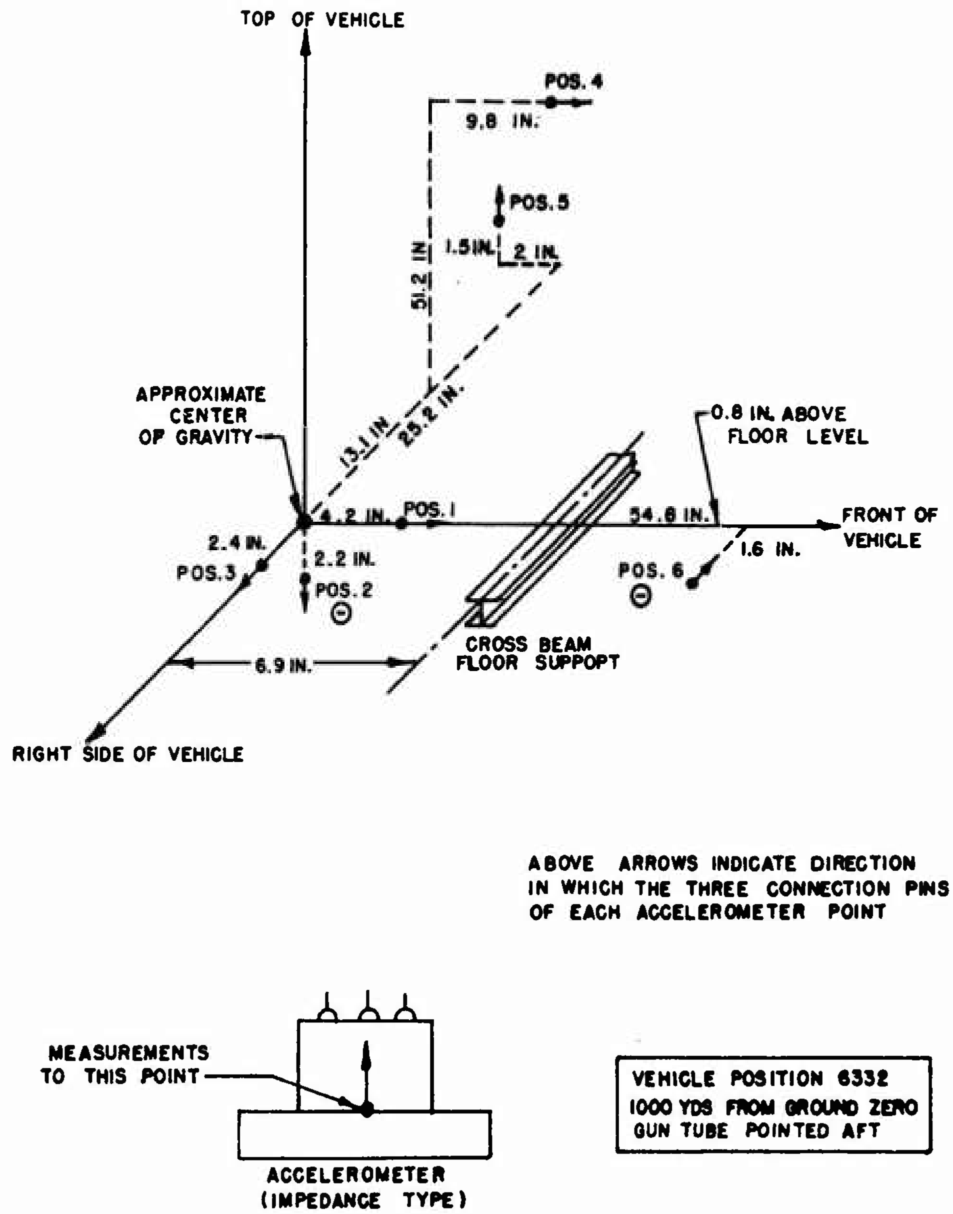


Fig. A.24 Accelerometer, Impedance Type, Location Diagram for Position 6332

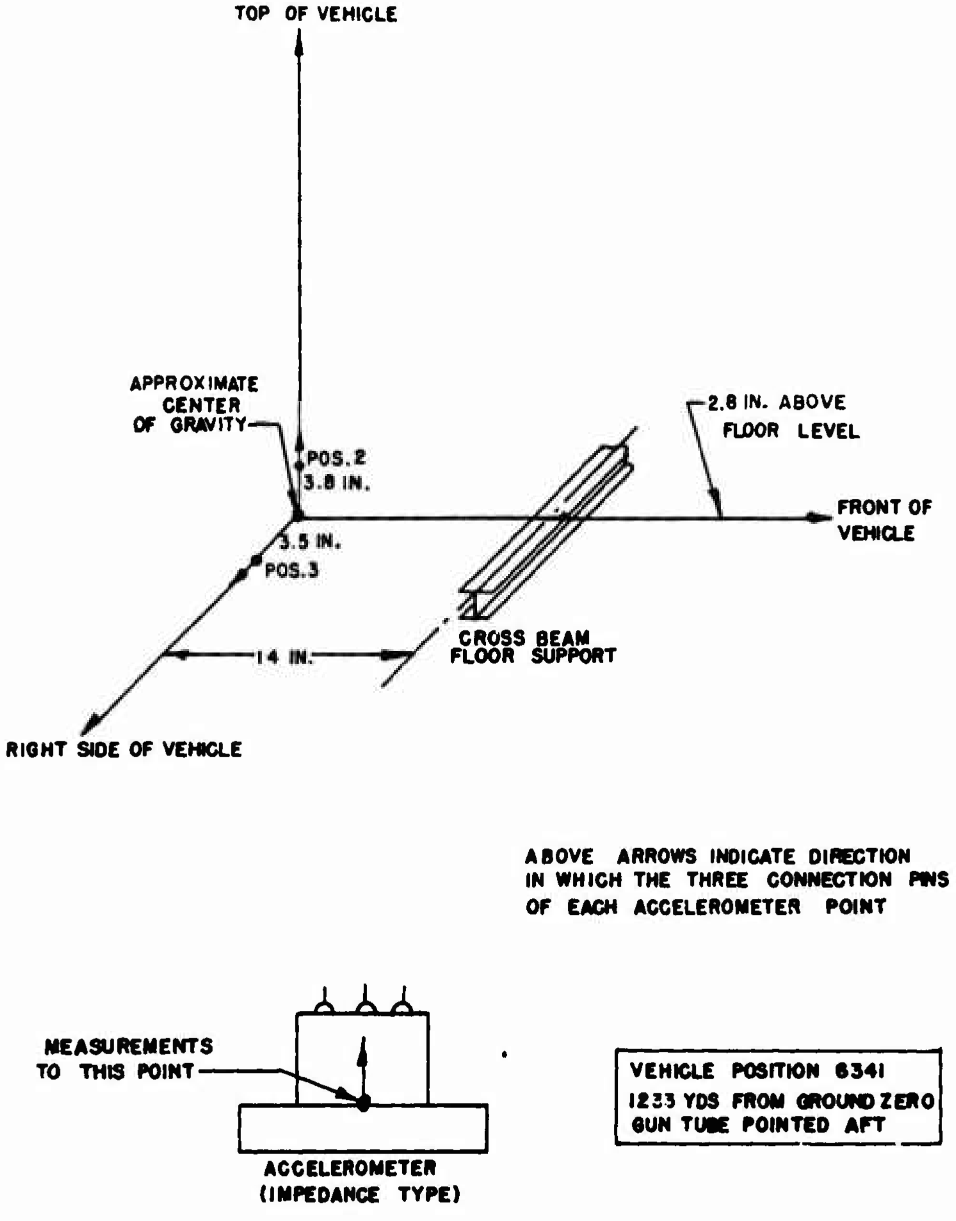


Fig. A.25 Accelerometer, Impedance Type, Location Diagram for Position 6341

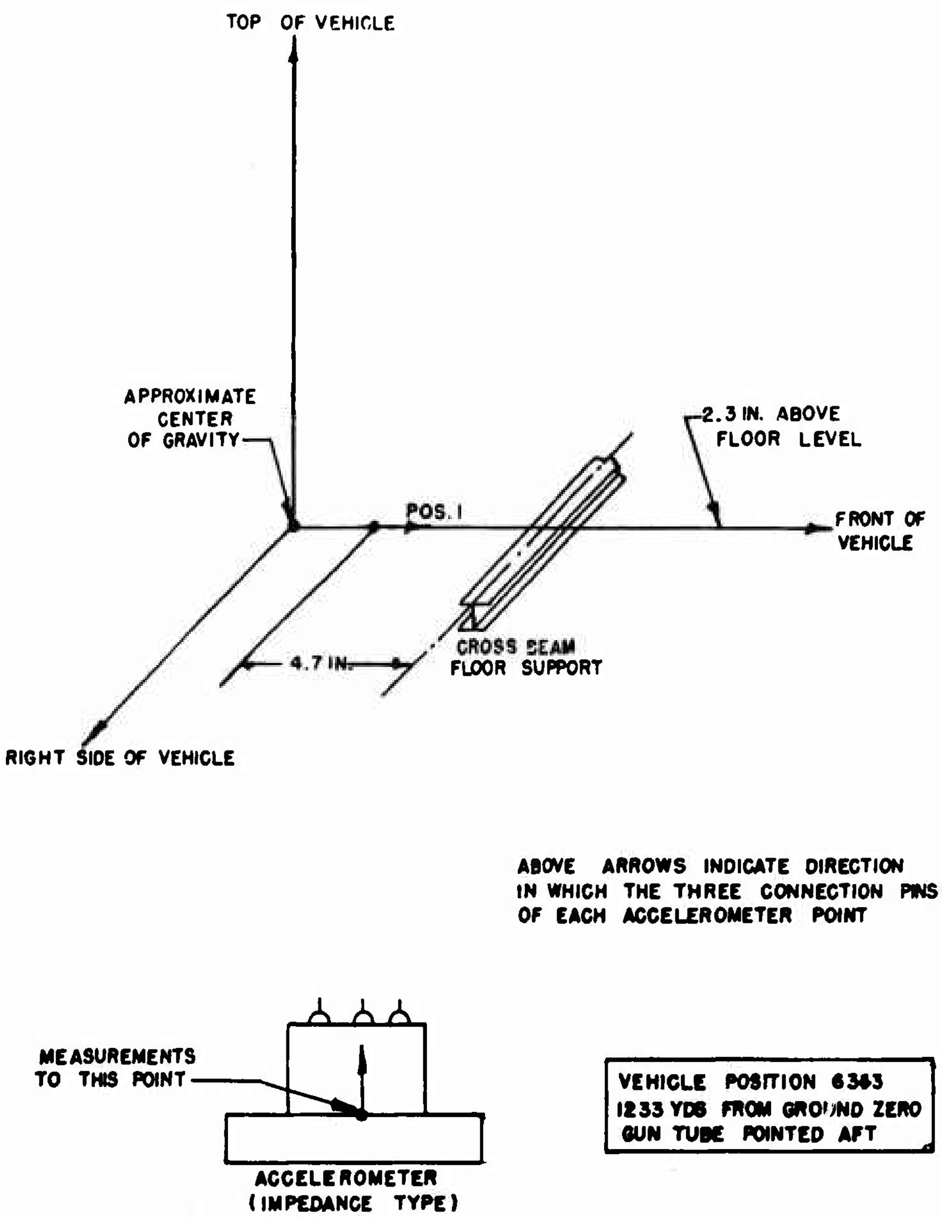
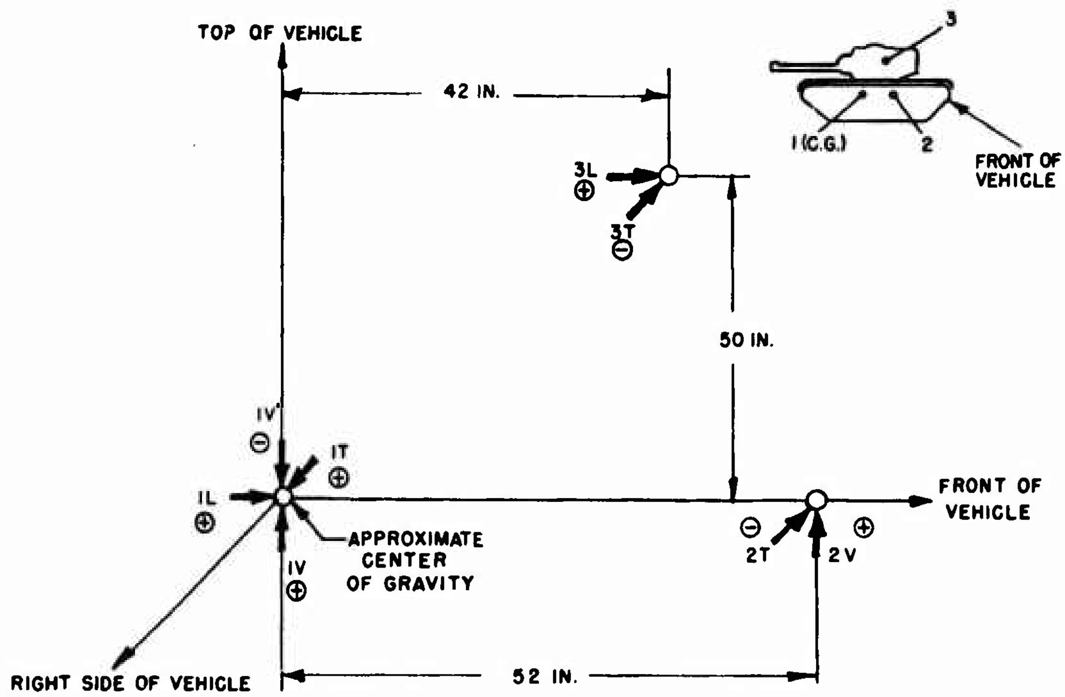


Fig. A.26 Accelerometer, Impedance Type, Location Diagram for Position 6343



VEHICLE POSITION	LEFT ELEMENT		RIGHT ELEMENT	
	LOCATION	RANGE	LOCATION	RANGE
6311	1T	100G	1V	30 G
6311	3T	100 G	3L	10 G
6312	1L	100 G	1V	10 G
6312	2T	30 G	2V	30 G
6321	1T	30 G	1V	10 G
6322	1L	10 G	1V	10 G
6323	1L	10 G	1V	10 G
6331	1T	10 G	1V	3 G
6332	1L	10 G	1V	3 G

Fig. A.27 Accelerometer, Self-recording Type, Location Diagram for All Gauges Used

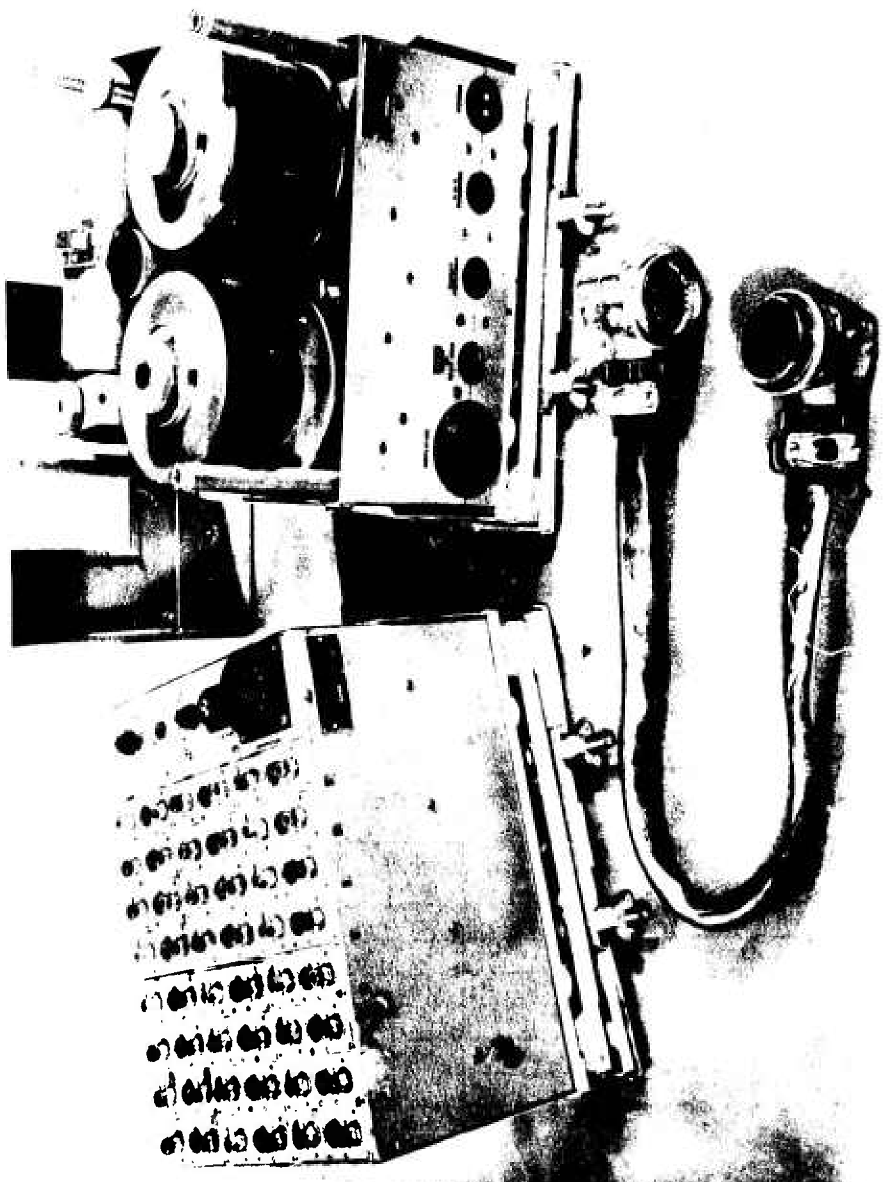


Fig. A.28 24-channel Gauge Amplifier Chassis and Magnetic Tape Recorder with Dust Cover Removed, Shown with Interconnecting Cable

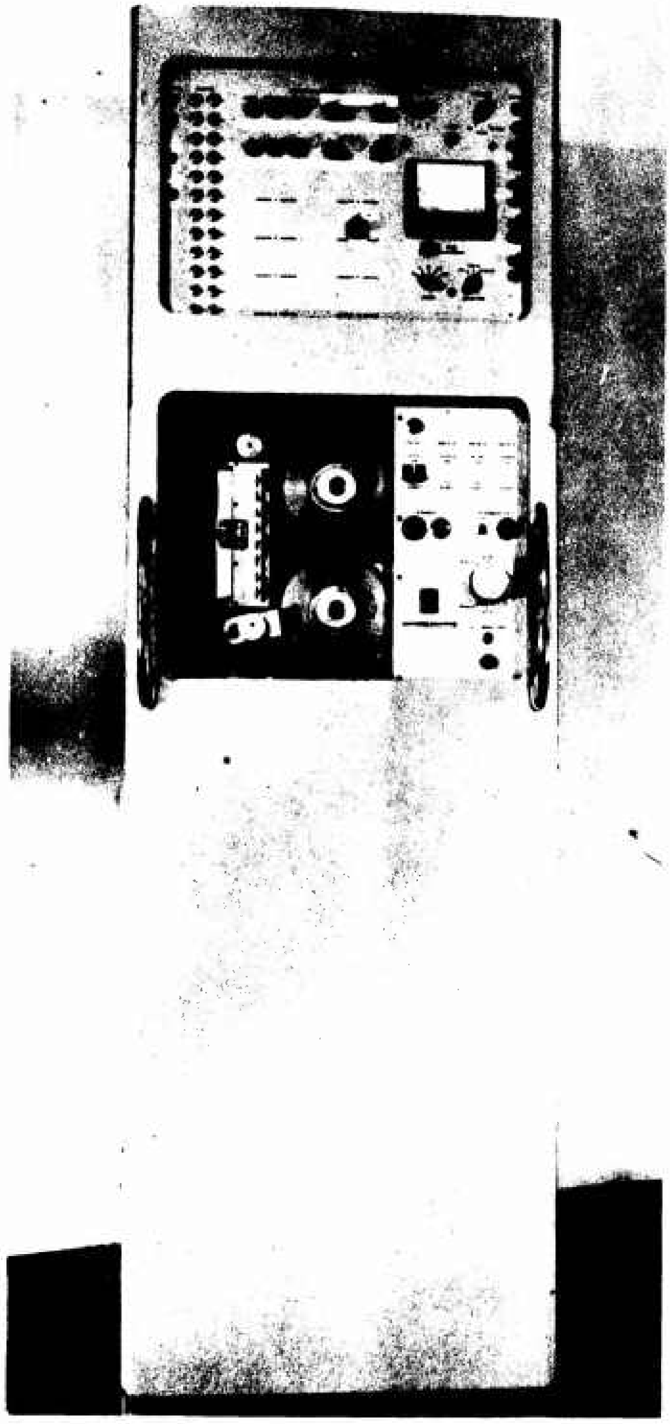


Fig. A.29 2-channel Playback Unit Used for Playback of 24-channel Magnetic Tape Records

Fig. A.30 Two Control Units, One with Cover in Place Showing Various Tests and Manual Operating Switches; the Other with Cover Removed Showing the Two Timing Motors at the Left, Stepping Relay in the Center, and Various Control Relays at the Right

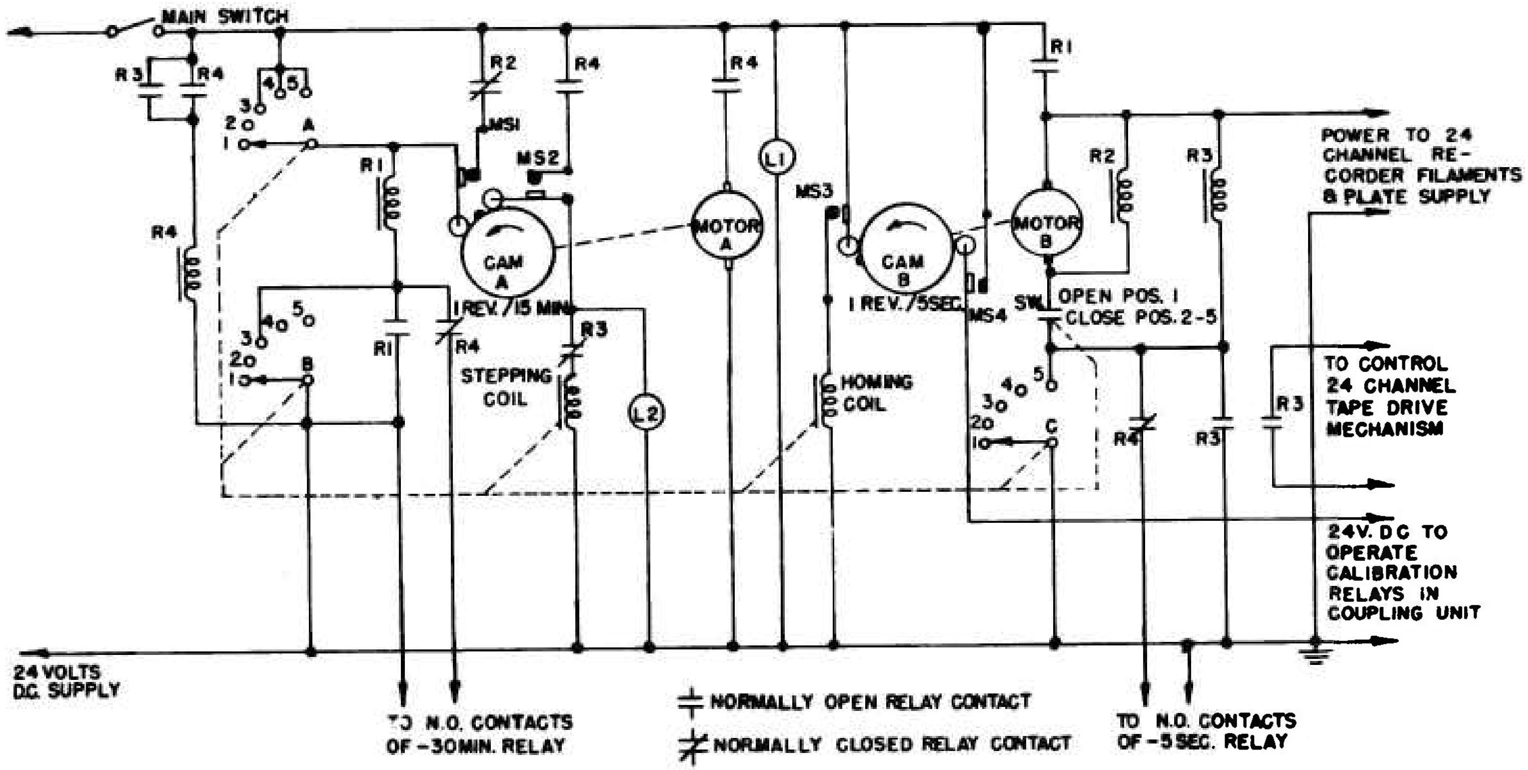


Fig. A.31 Control Units, Schematic Diagram Showing Cams A and B, Associated Cam Switches, and the Stepping Relay in Respective Starting Positions

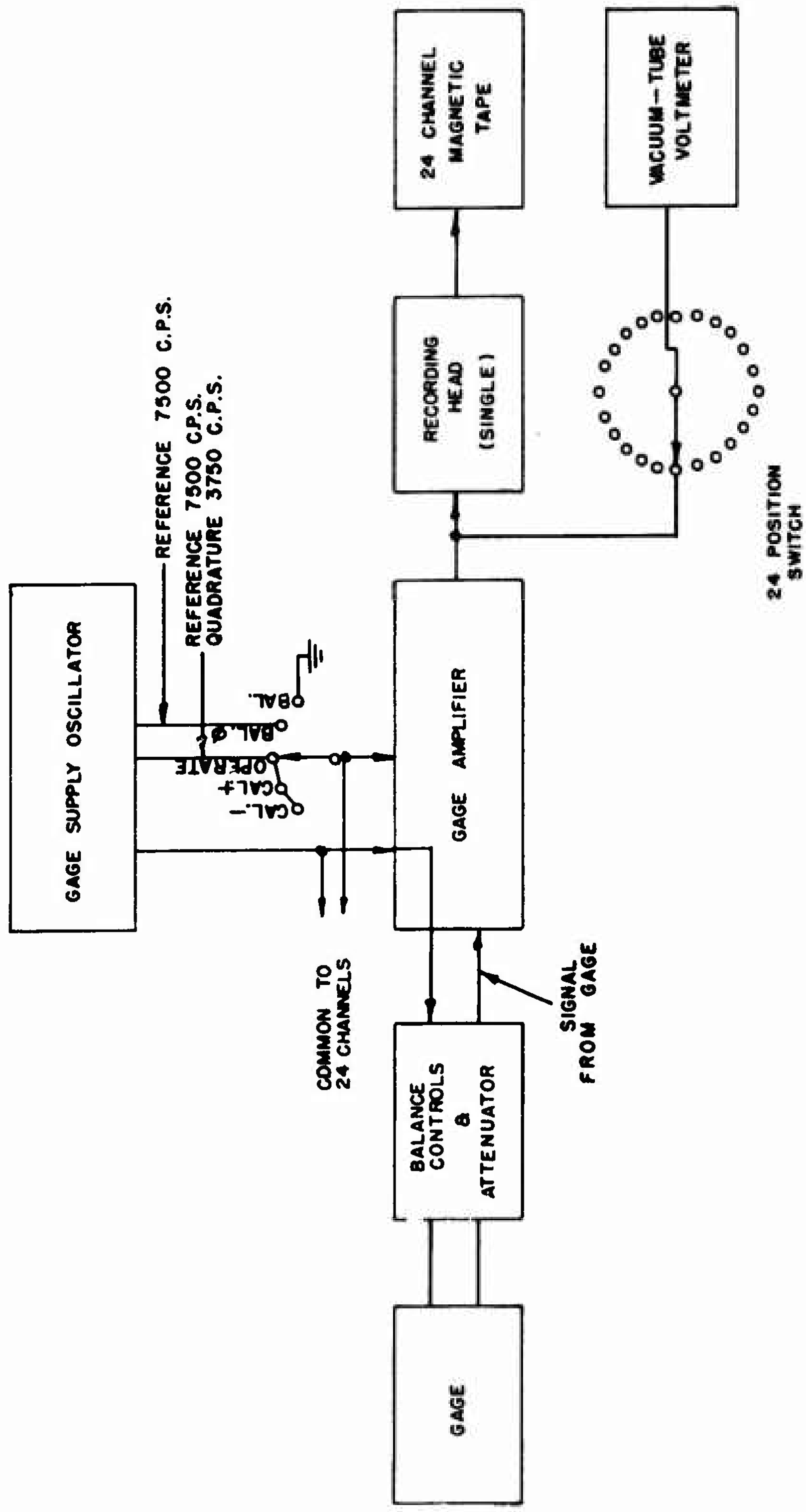


Fig. A.32 24-channel Magnetic Tape Recorder System, Block Diagram

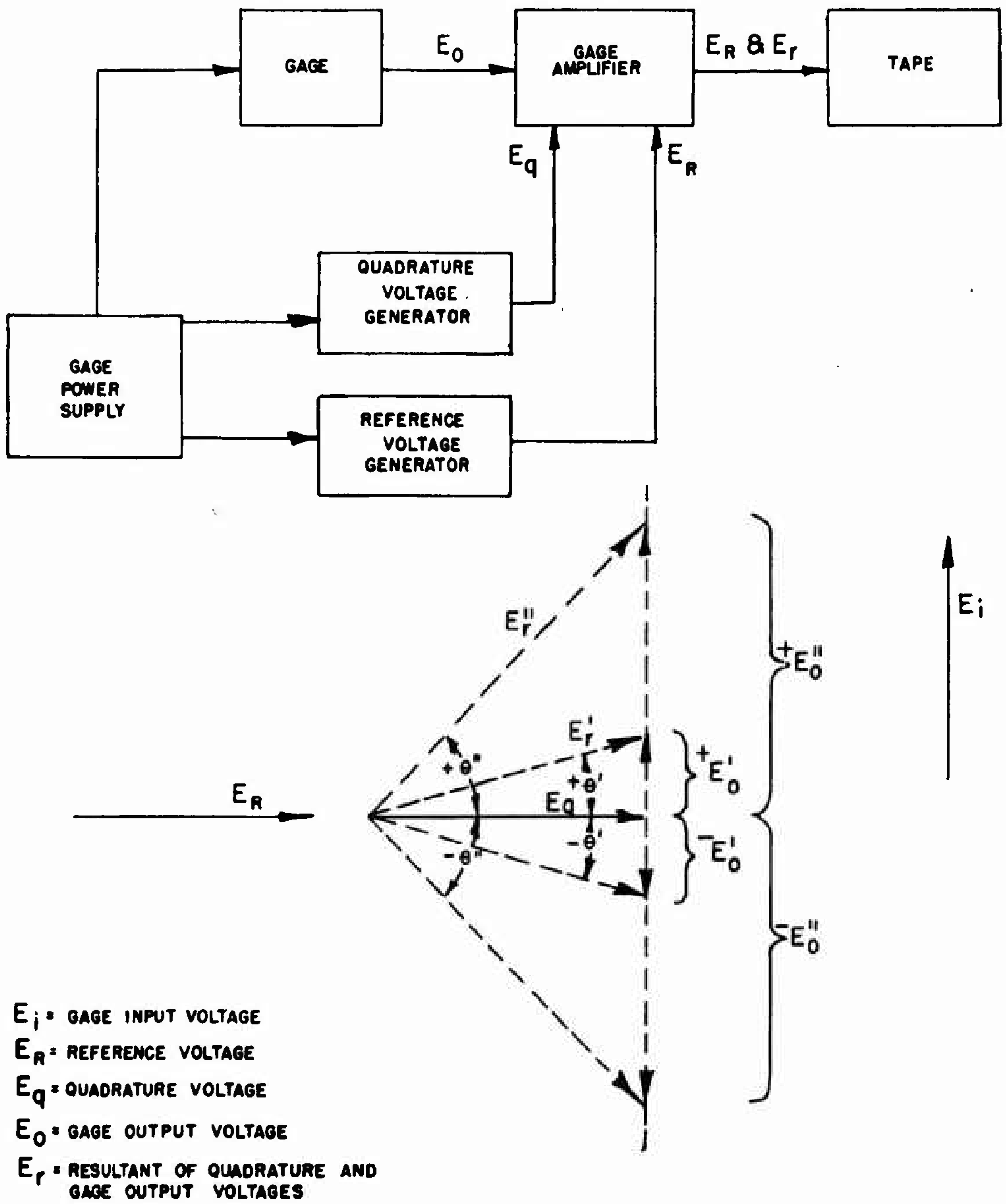


Fig. A.33 24-channel Magnetic Tape Recorder, Simplified Block Diagram and Vector Diagram, Showing Phase Relationships of Signal Components

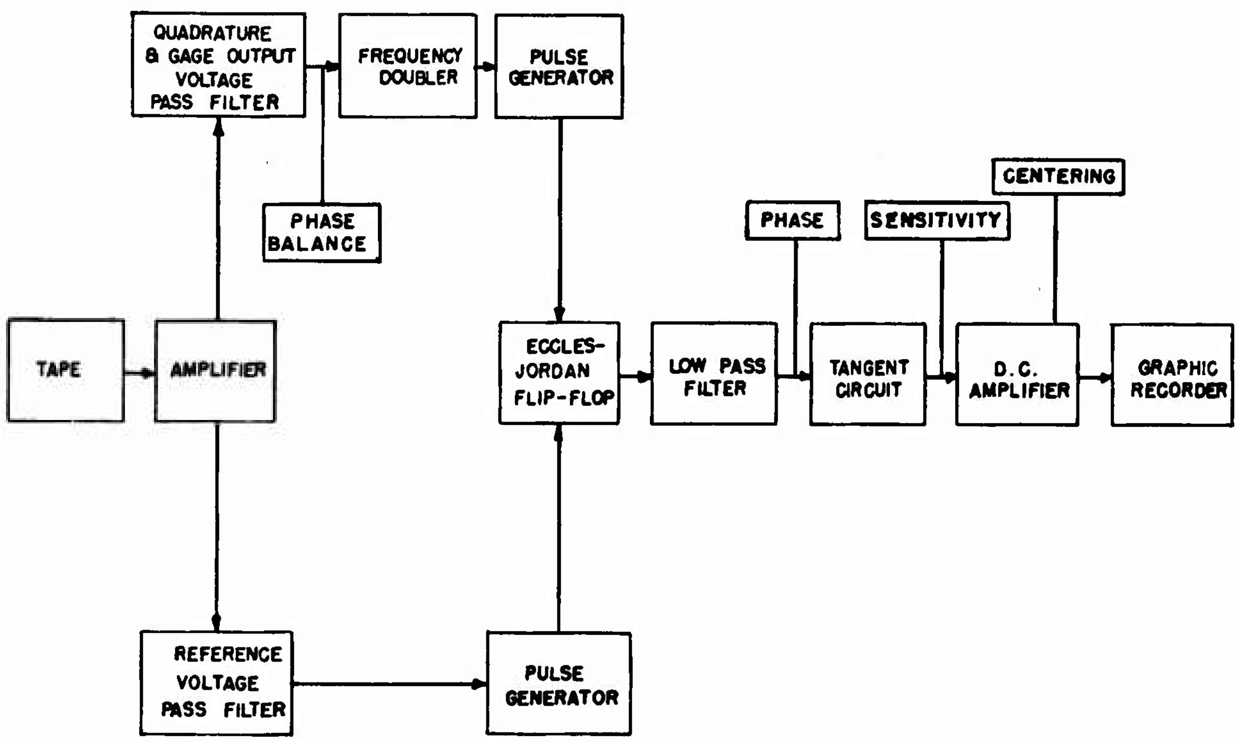


Fig. A.34 Block Diagram of 2-channel Playback System Used with 24-channel Magnetic Tape Recorder

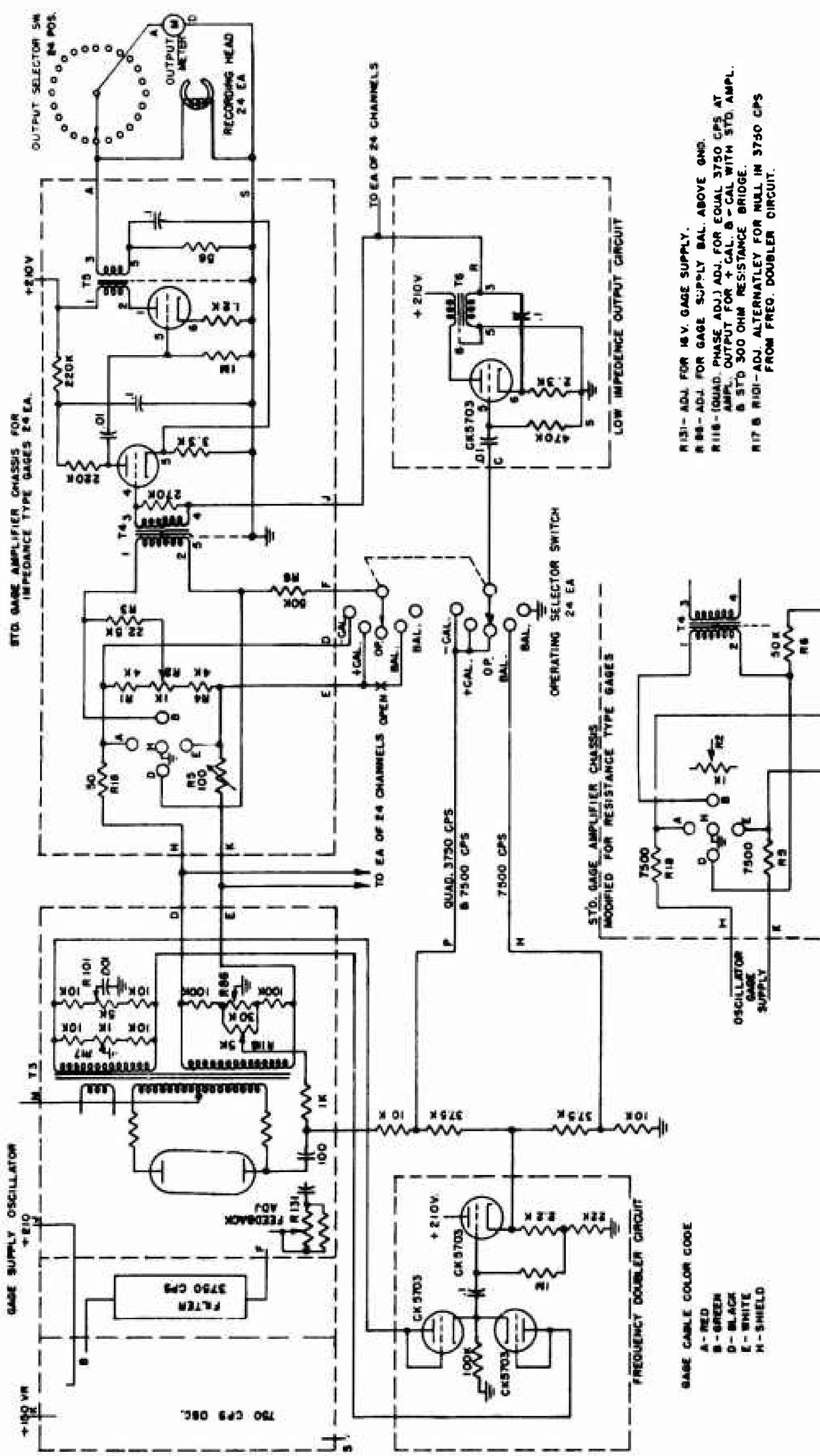


Fig. A.35 24-channel Magnetic Tape Recorder System, Schematic Wiring Diagram Showing All Operating Controls and Adjustments, As Well As Modifications Required for Use with Resistance Type Gauges

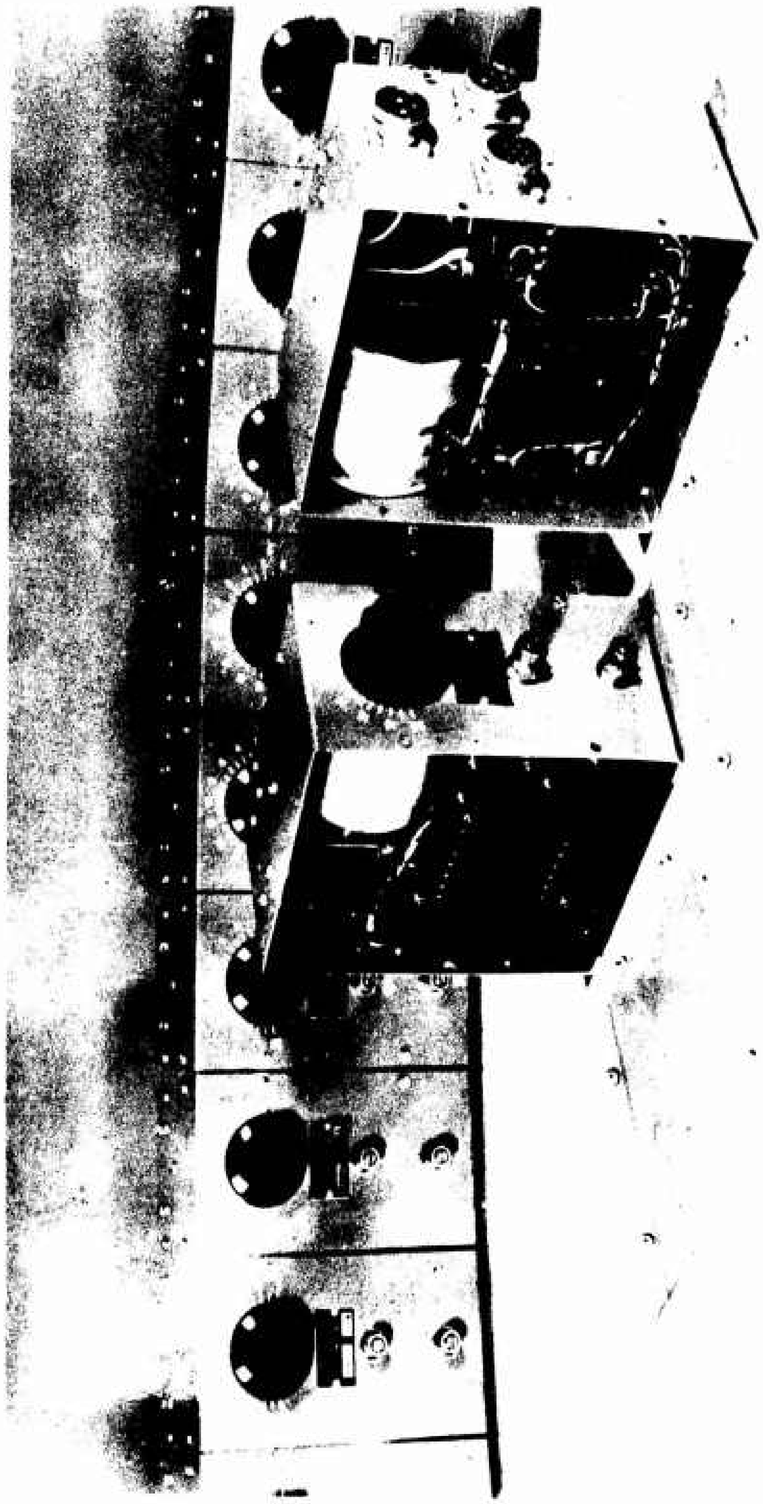


Fig. A.36 Coupling Units Used in Conjunction with Impedance Type Accelerometers and Pressure Gauges, Showing Attenuator Balancing Controls, Connectors, and Internal Wiring

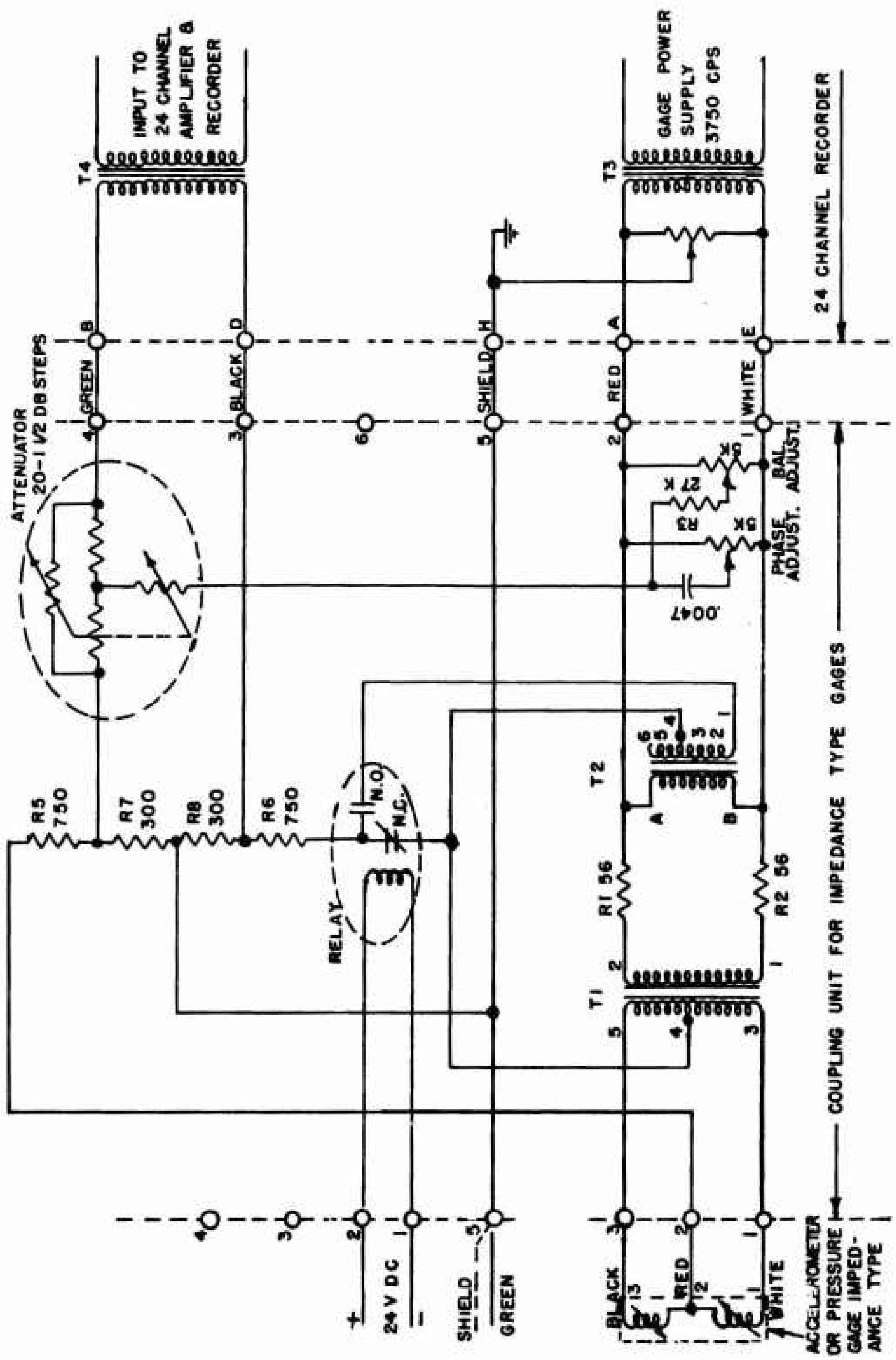


Fig. A.37 Coupling Unit for Impedance Type Accelerometers and Pressure Gauges, Schematic Wiring Diagram, Including Connections to Impedance Gauge and to Corresponding Gauge Amplifier Input

Fig. A.38 7-channel Resistance Gauge Balancing Unit Used with 24-channel Magnetic Tape Recorder, Showing Two Balancing Controls, and Input and Output Connectors for Each Channel

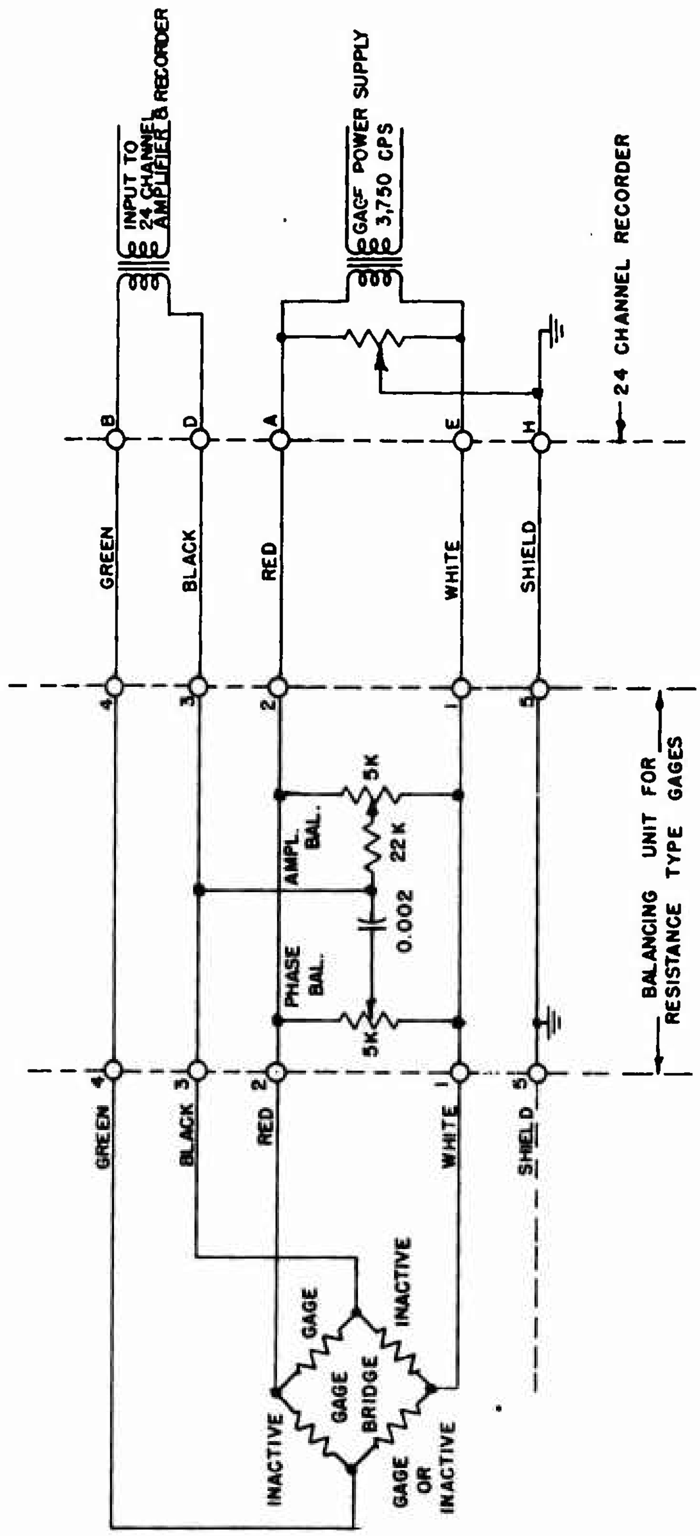


Fig. A.39 7-channel Resistance Gauge Balancing Unit, Schematic Wiring of Signal Channel Showing Connections to Resistance Gauge Circuit and Input of 24-channel Magnetic Tape Recorder Gauge Amplifier

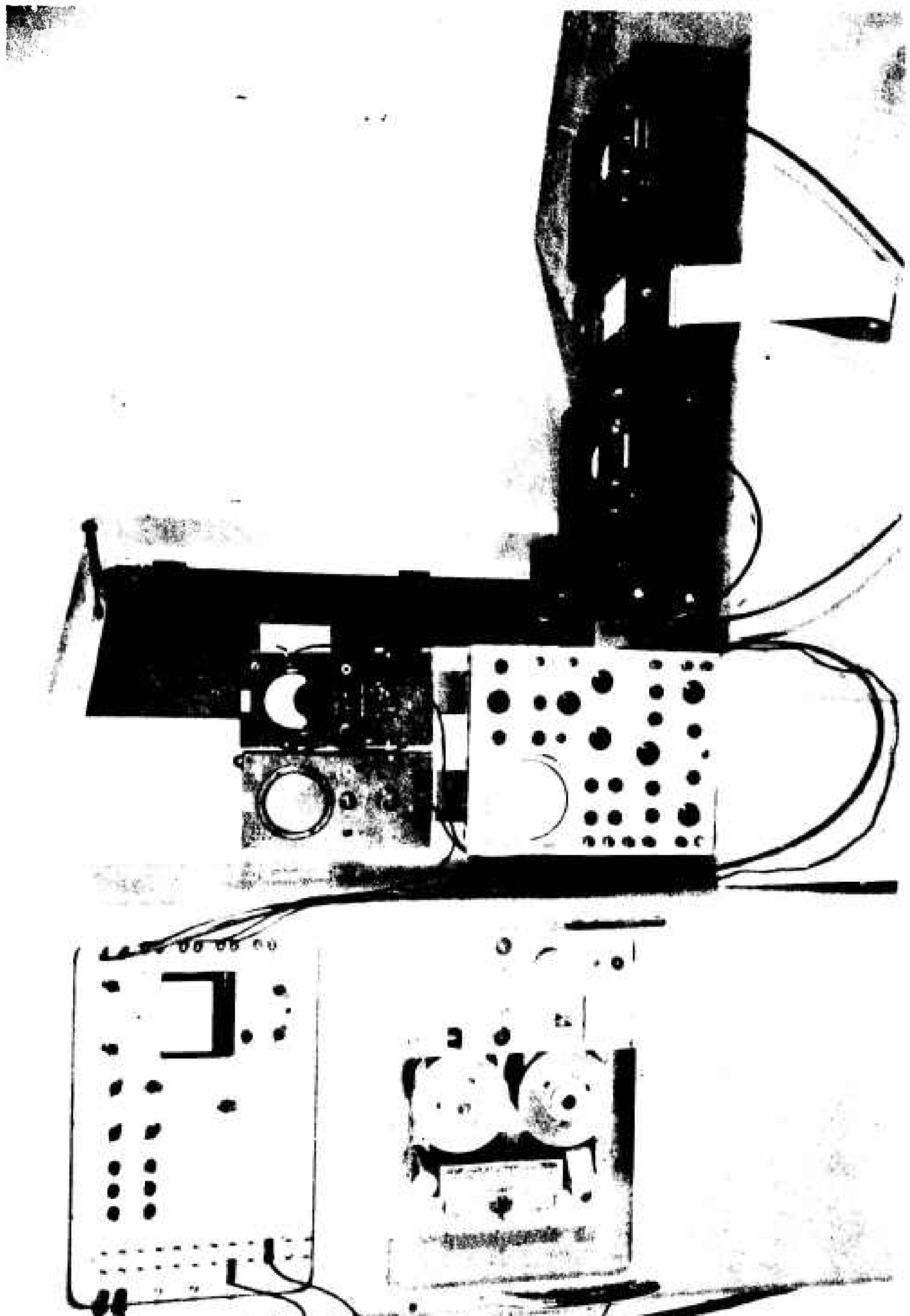


Fig. A.40 2-channel Playback System Setup Used with 24-channel Magnetic Tape Recorder

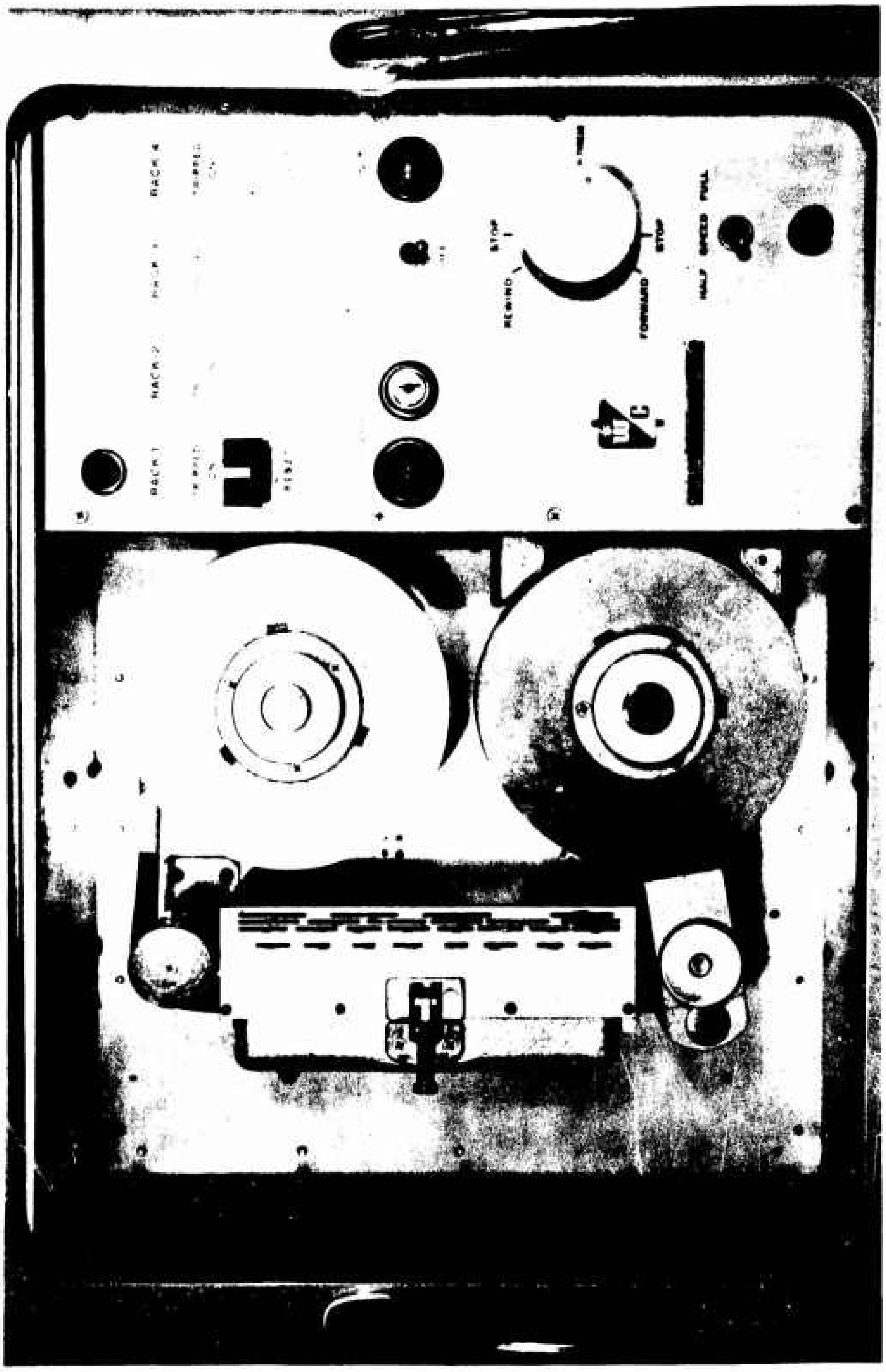


Fig. A.41 Playback Mechanism of 2-channel Playback Equipment Used with 24-channel Magnetic Tape Recorder

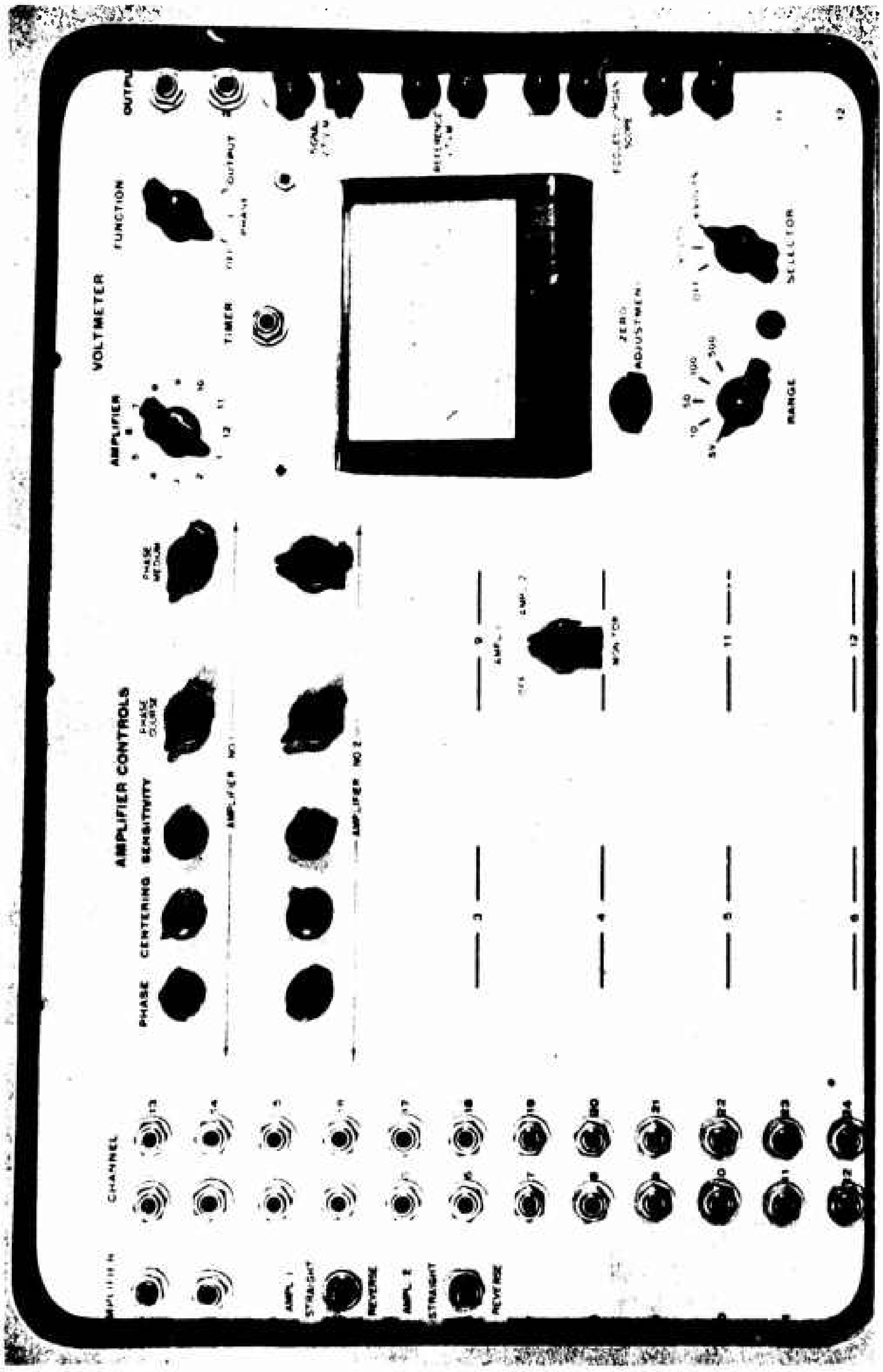


Fig. A.42 Control Panel of 2-channel Playback Equipment Used with 24-channel Magnetic Tape Recorder

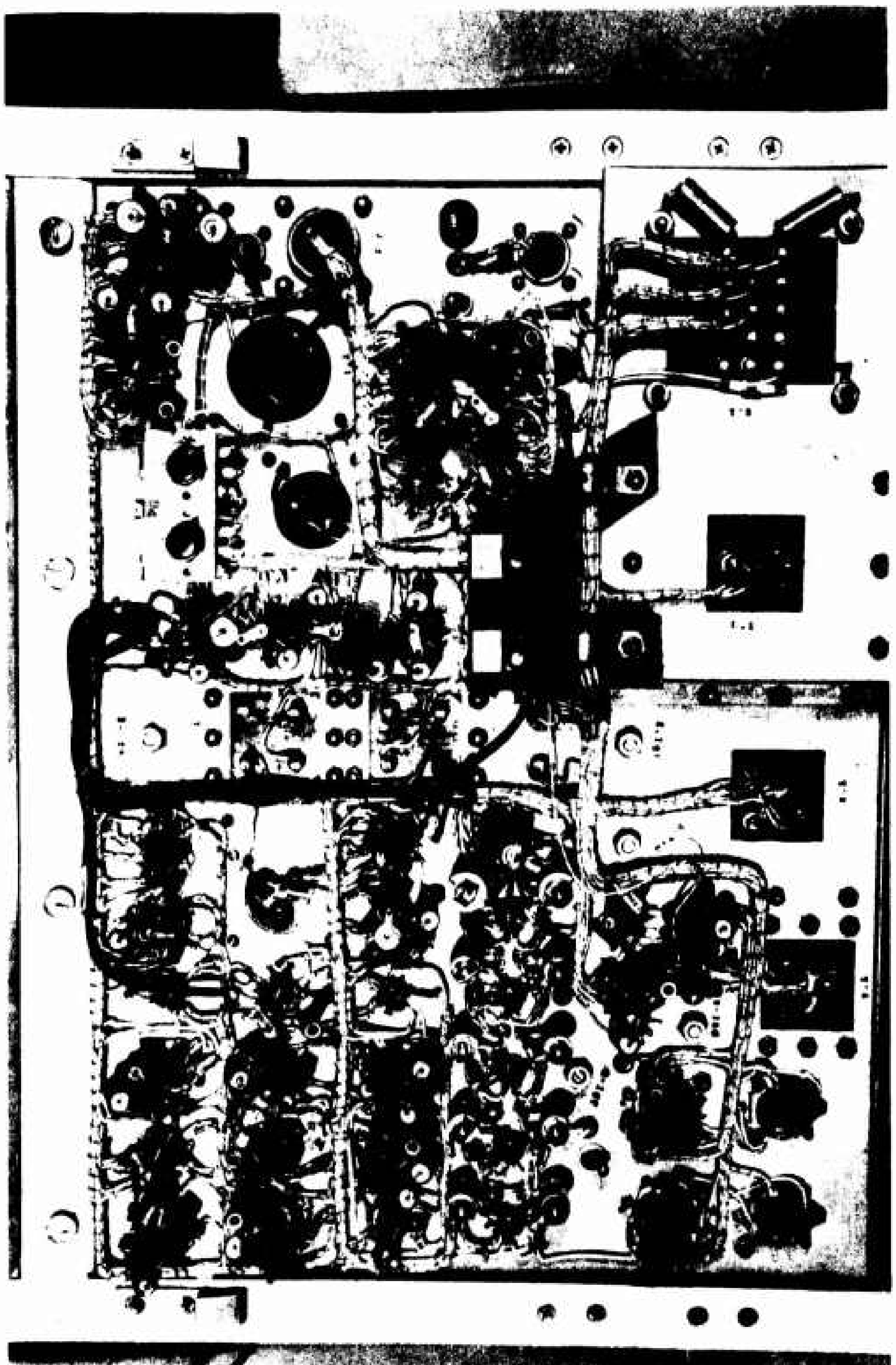


Fig. A.43 Playback Amplifier (One of Two) of 2-channel Playback Equipment Used with 24-channel Magnetic Tape Recorder

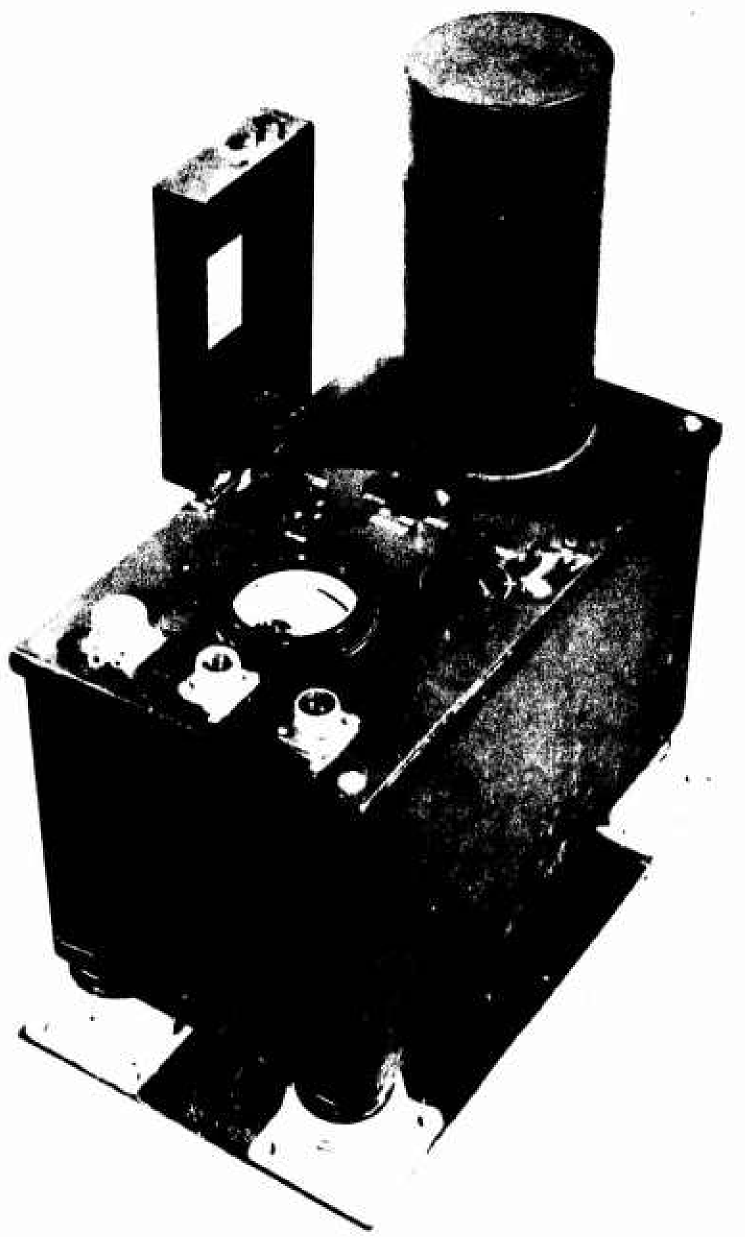


Fig. A.44 Ionizing Radiation Monitor Used with 24-channel Magnetic Tape Recorder

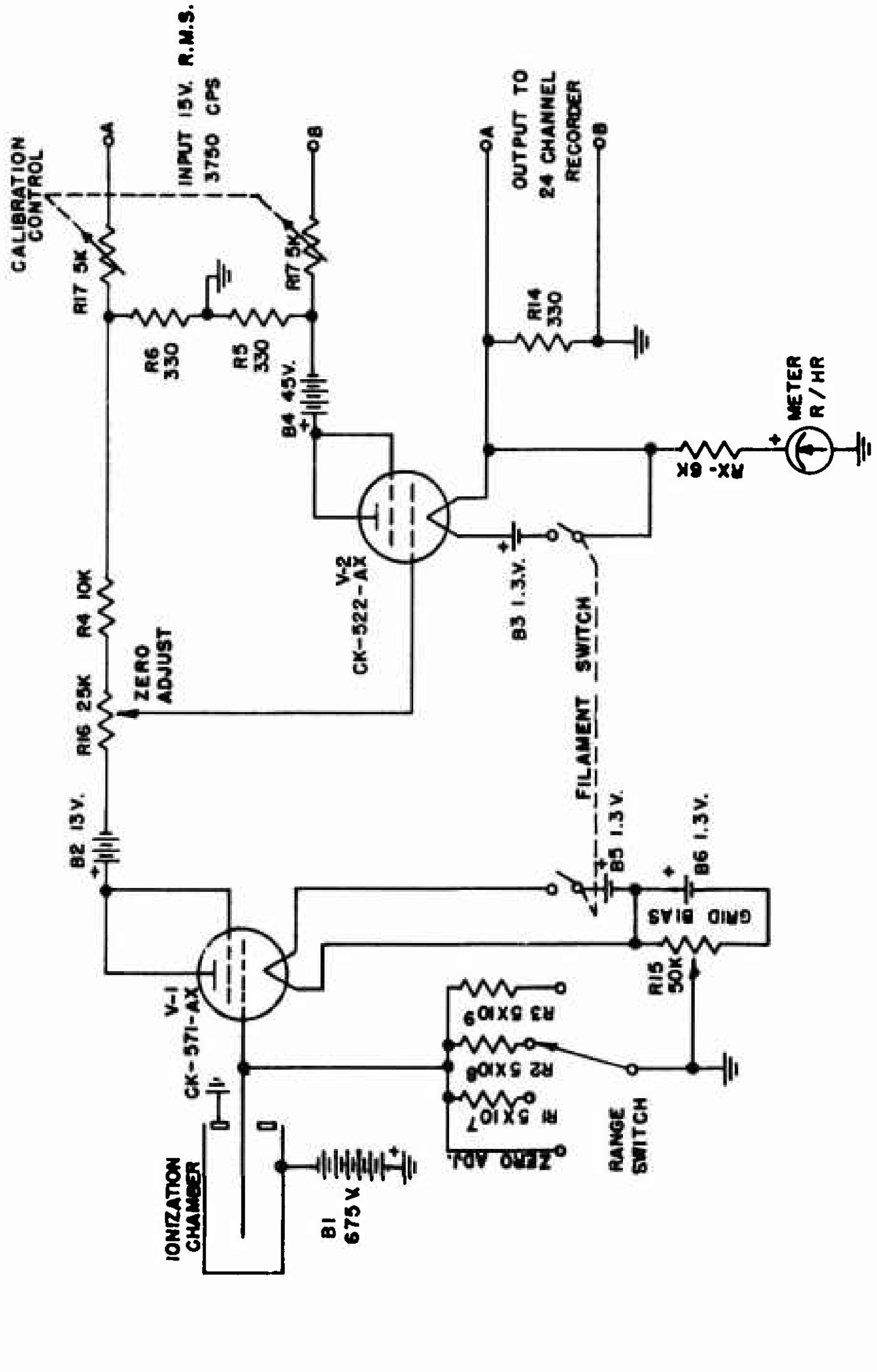


Fig. A.45 Schematic Wiring of Ionizing-radiation Monitor Used with 24-channel Magnetic Tape Recorder

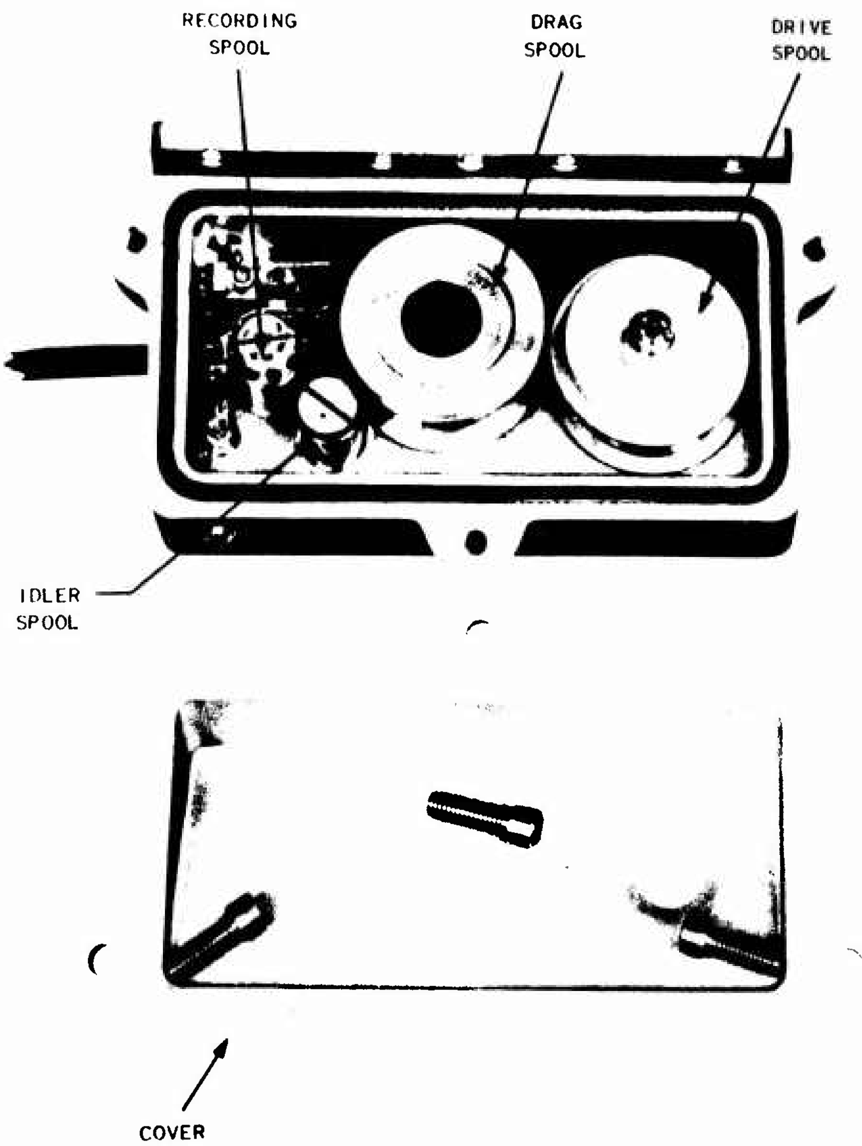


Fig. A.46 Accelerometer, Self-recording Type, with Main Cover Removed Showing Tape Mechanism, Seismic Elements, and Torsion Timer

Fig. A.47 Accelerometer, Self-recording Type, with Main Cover Removed Showing Tape in Place Ready for Recording

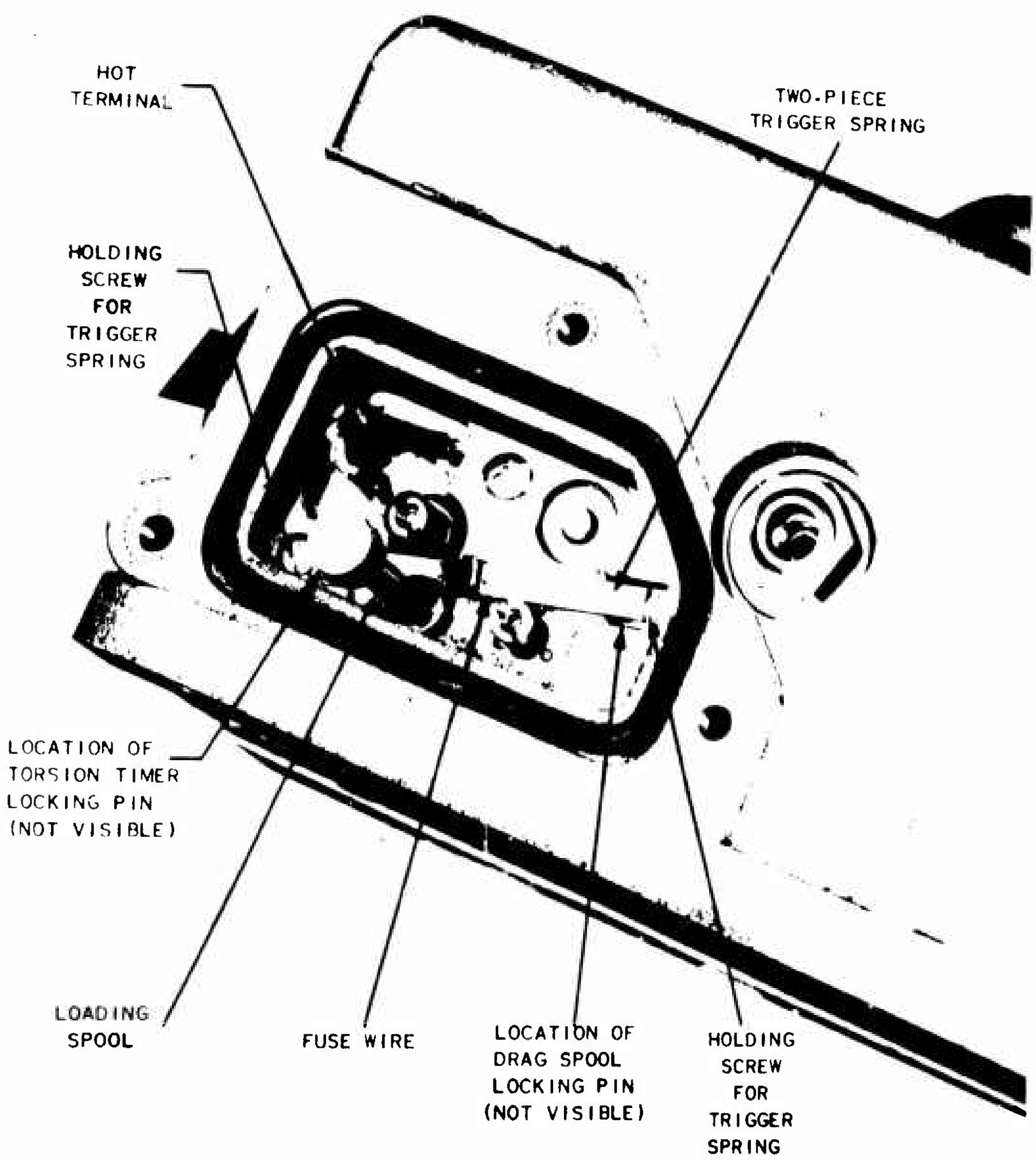


Fig. A.48 Accelerometer, Self-recording Type, with Cover Removed from Firing Compartment Showing Fuse Wire in Place over Trigger Spring

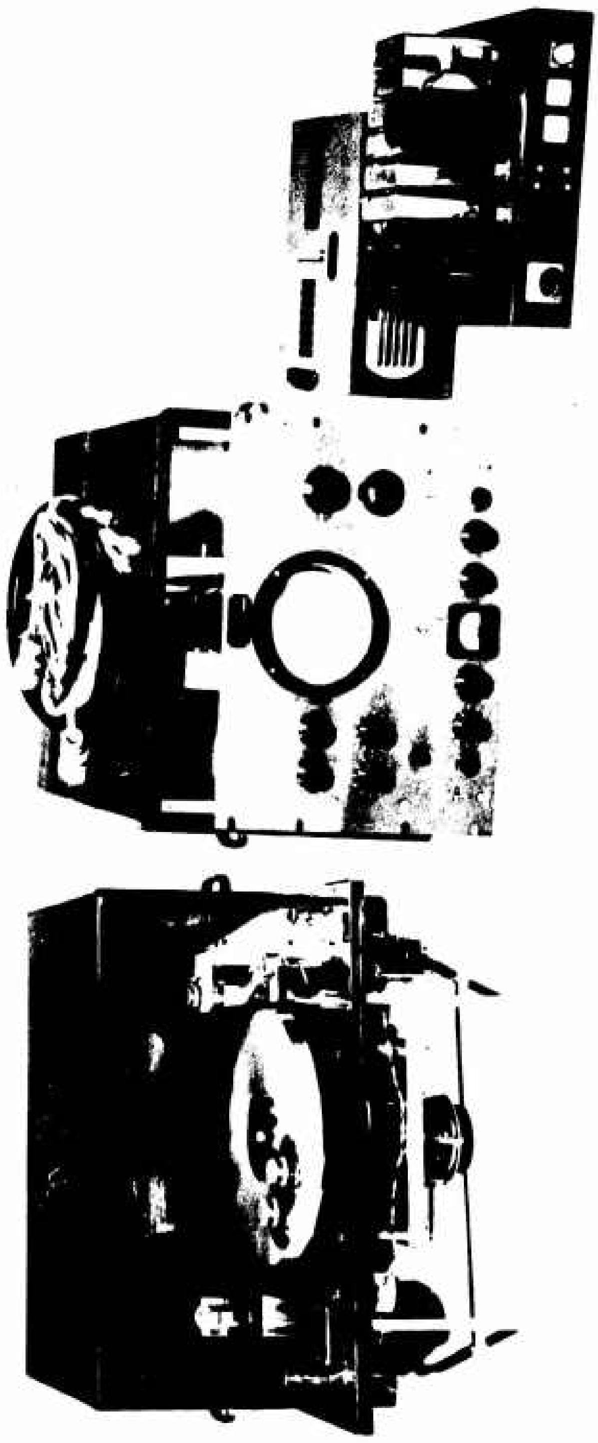


Fig. A.49 Accelerometer, Self-recording Type, Playback Equipment with Covers Removed Showing Mechanical Playback Unit, Electronic Display Unit, and Power Supply Unit

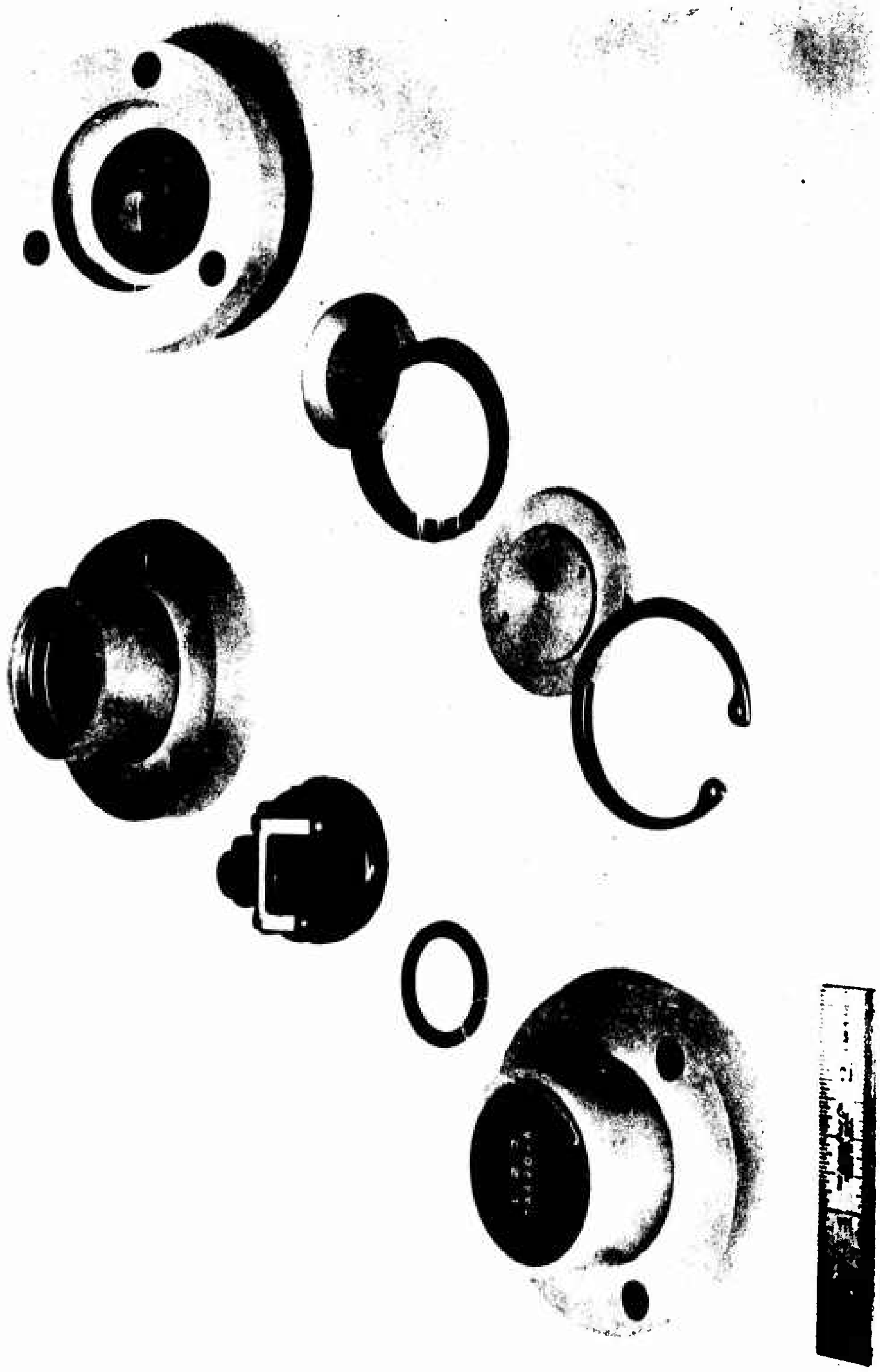


Fig. A.50 Accelerometer, Impedance Type, One Completely Assembled, a Second with Gauge Element Assembly Removed, and a Third with Oil Diaphragm Assembly Removed

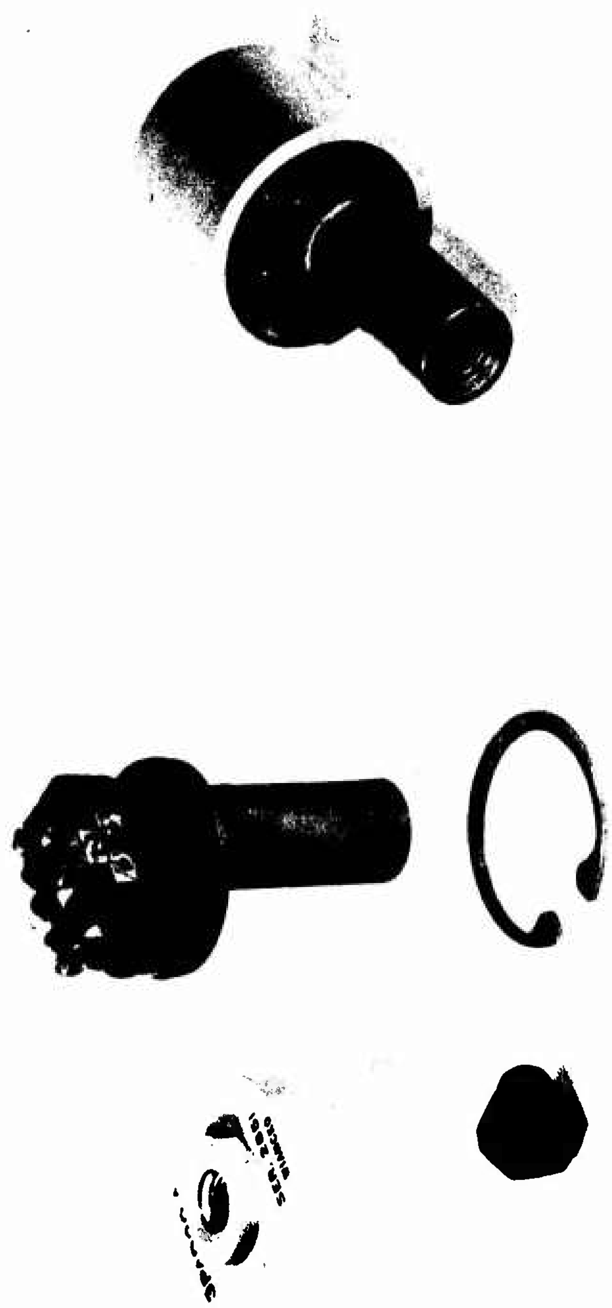


Fig. A.51 Pressure Gauge, Impedance Type, One Shown with Cover over Gauge Element Removed, Together with Bleeder Plug and Steel Retaining Ring; the Second Shown Assembled Ready for Use

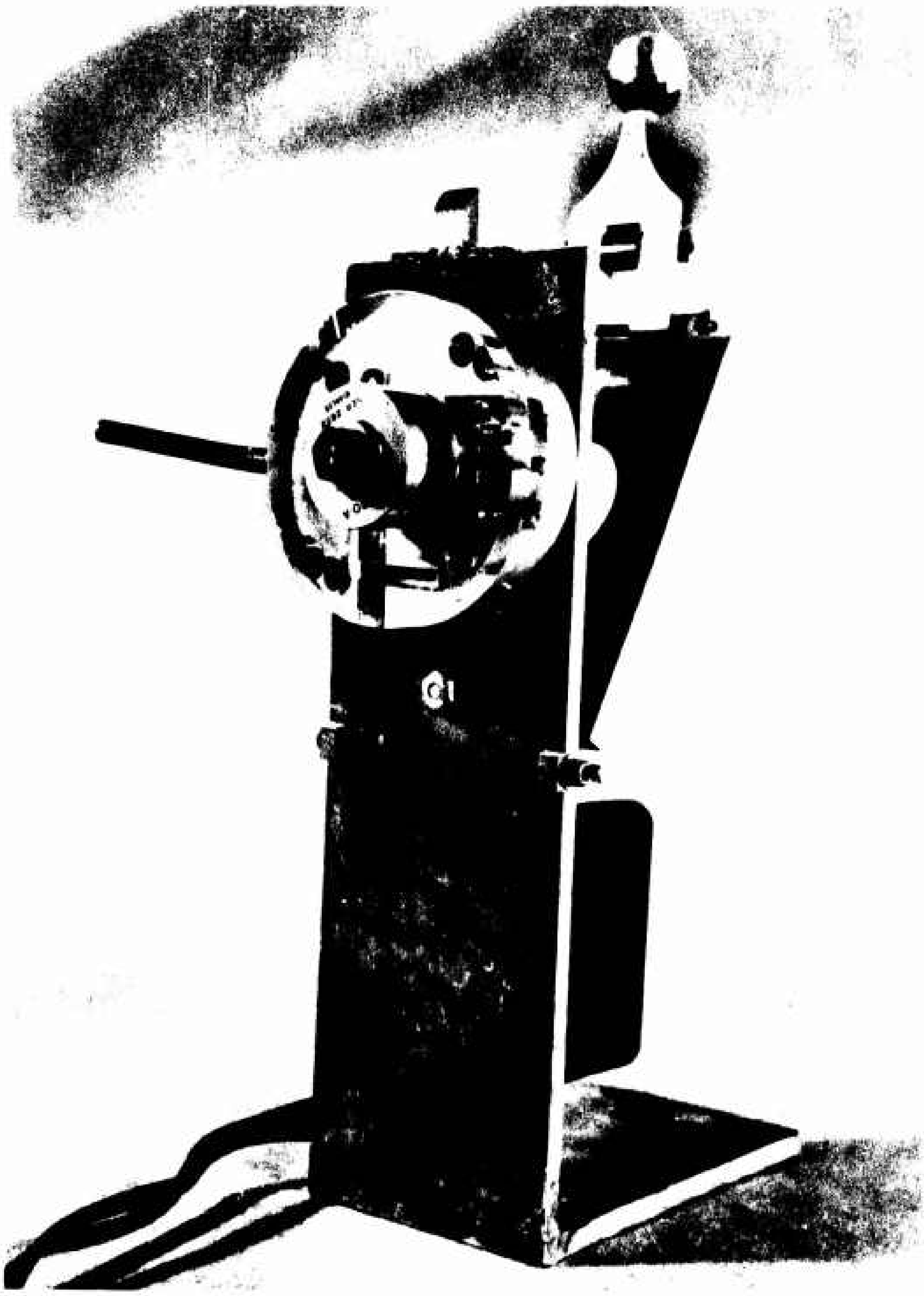


Fig. A.52 Pressure Gauge, Impedance Type, Test Fixture Used for Determining Response Characteristics of Gauge; Pressure Gauge Secured in Position for Testing

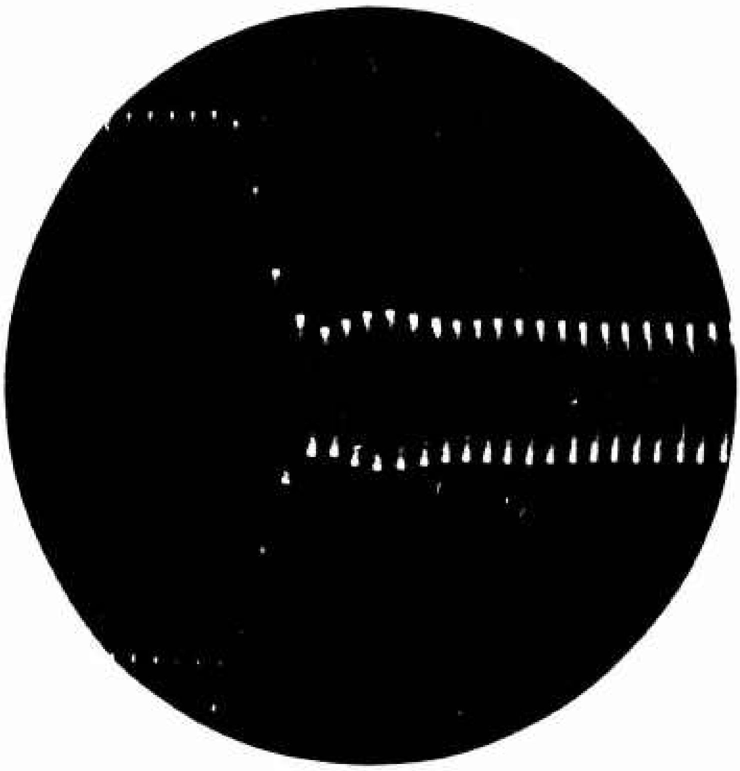


Fig. A.53 Pressure Gauge, Impedance Type, Typical Response Record

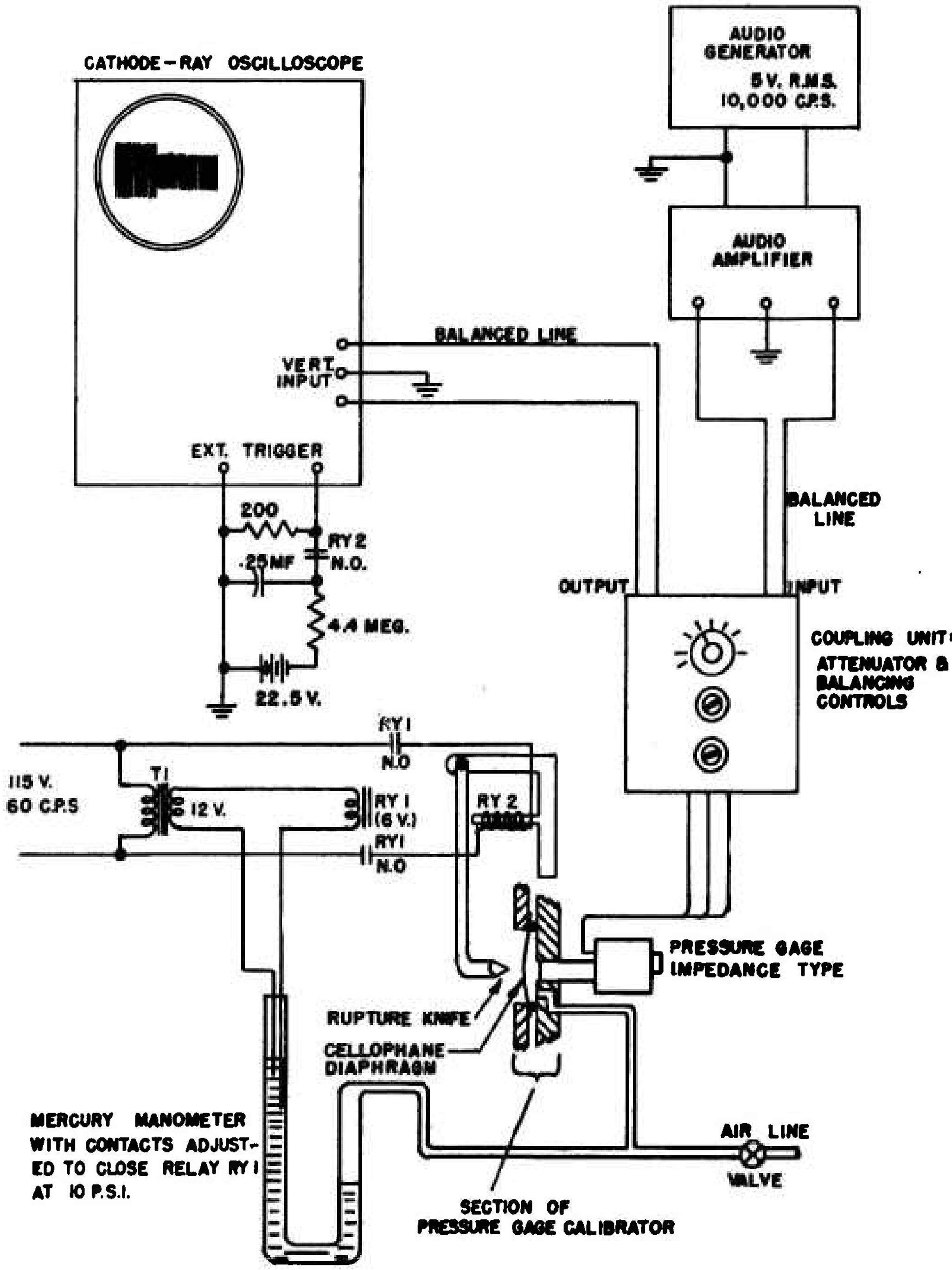


Fig. A.54 Test Arrangement for Determining Response Characteristic of Impedance Type Pressure Gauges

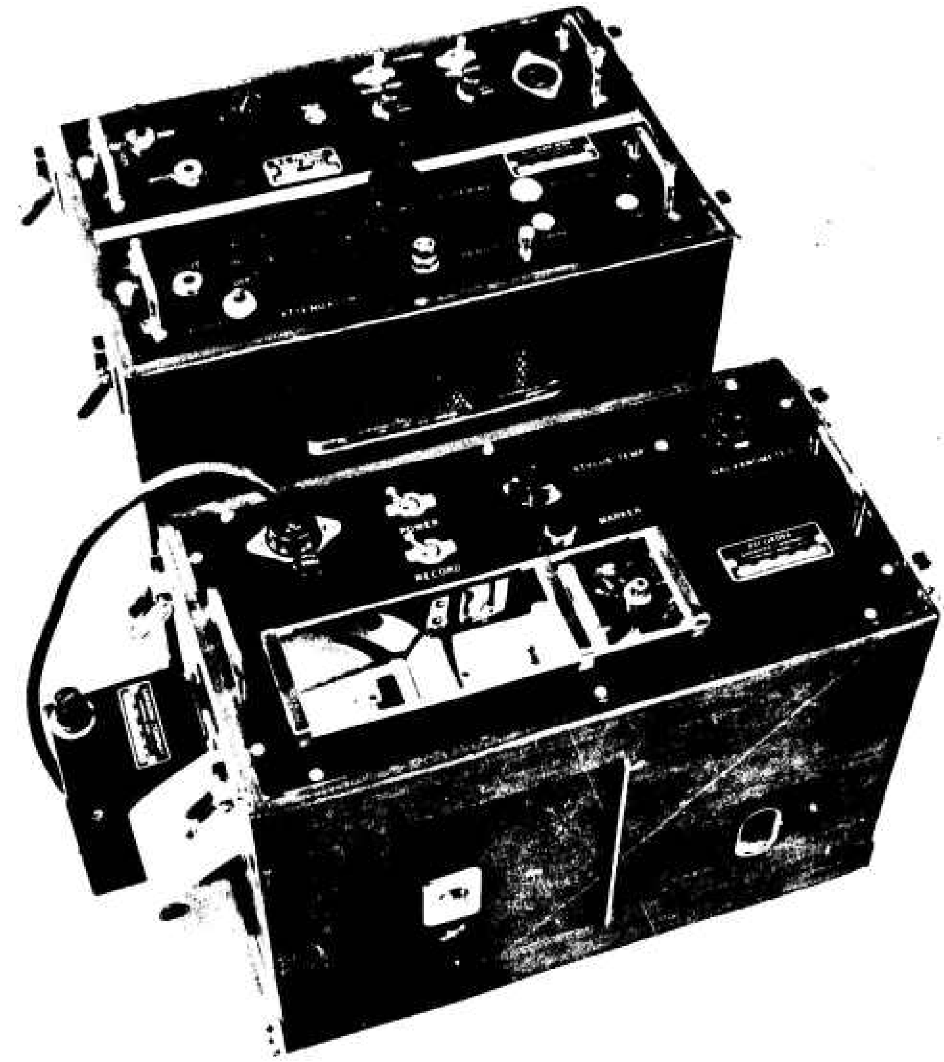


Fig. A.55 D-c Amplifier and Associated Recorder with Paper Take-up Unit

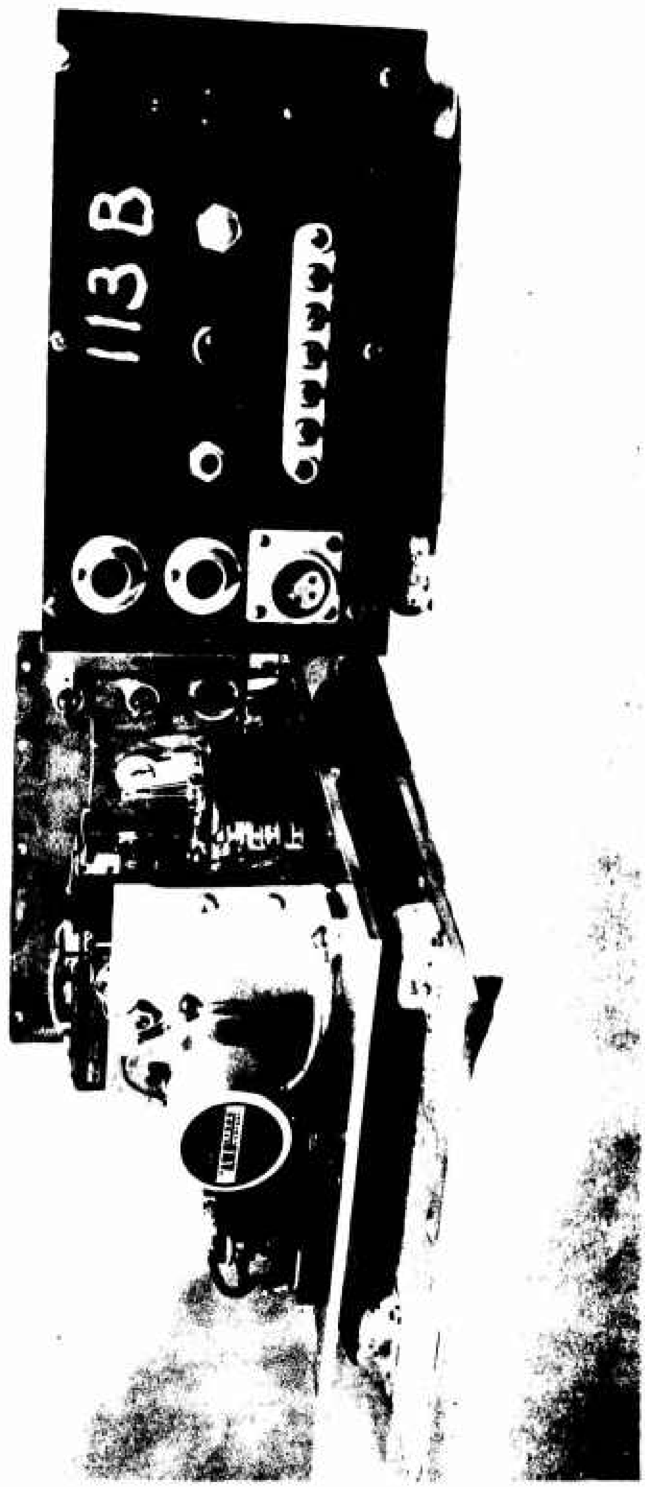


Fig. A.56 Calibration Units (Two) Used with D-c Amplifier Recorder System

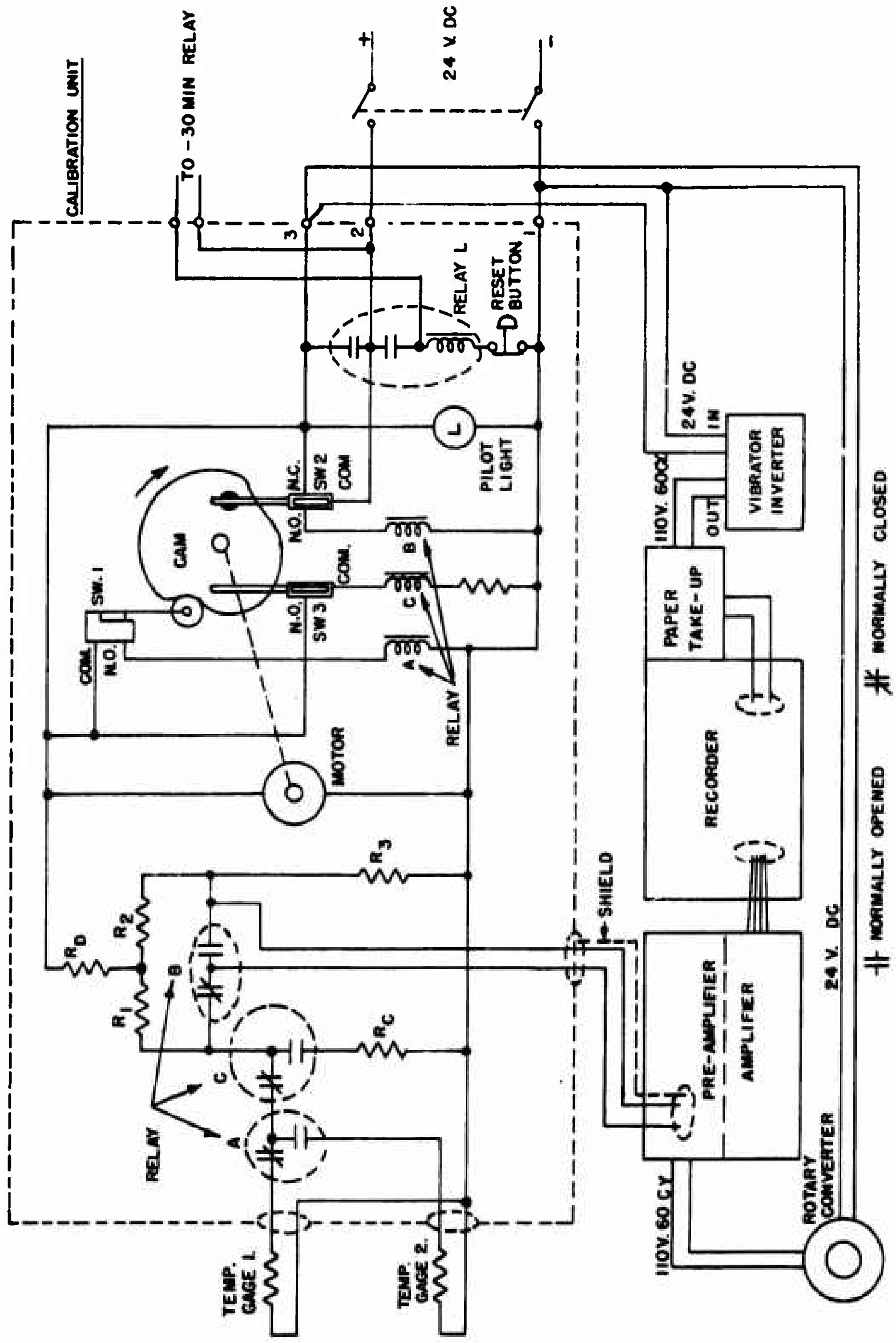


Fig. A.57 Calibration Unit Schematic Wiring Shown with Connections to Other Components of the D-c Amplifier Recorder System

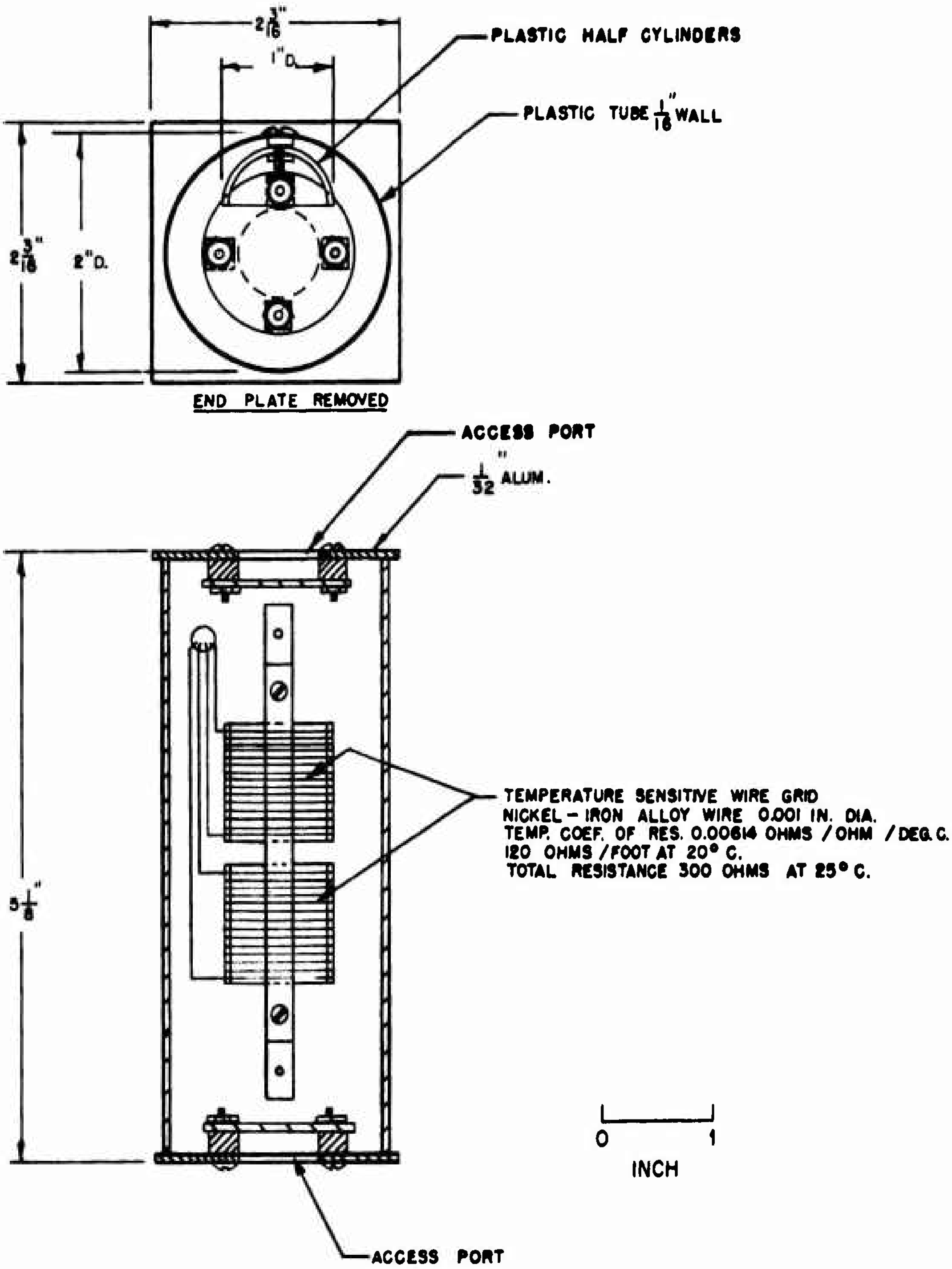


Fig. A.58 Mechanical Details of the Resistance-wire Air-temperature Gauge

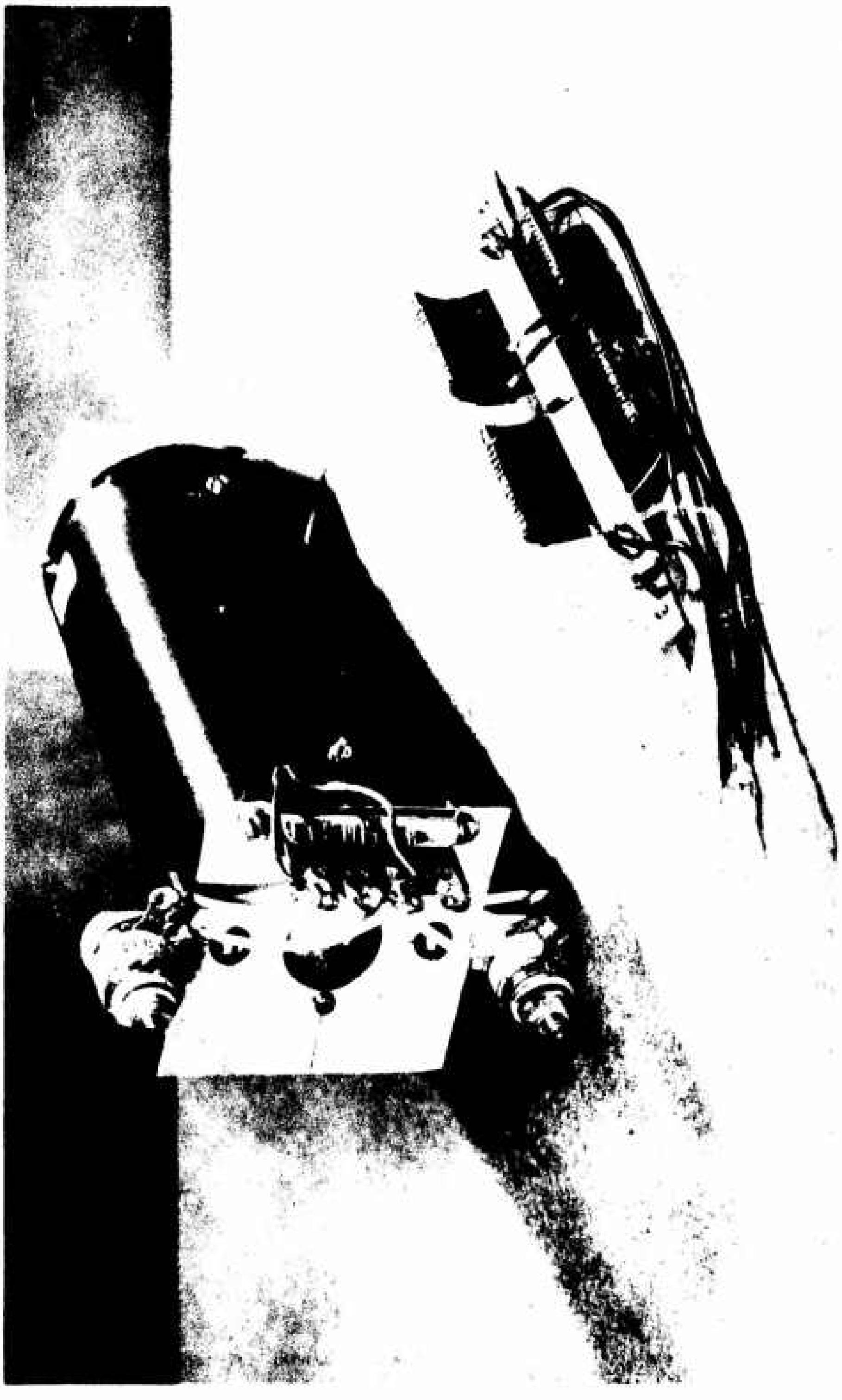


Fig. A.59 Resistance-wire Air-temperature Gauge Shown Complete with Fixed Bridge Elements, Together with the Active Element Assembly of a Second Gauge

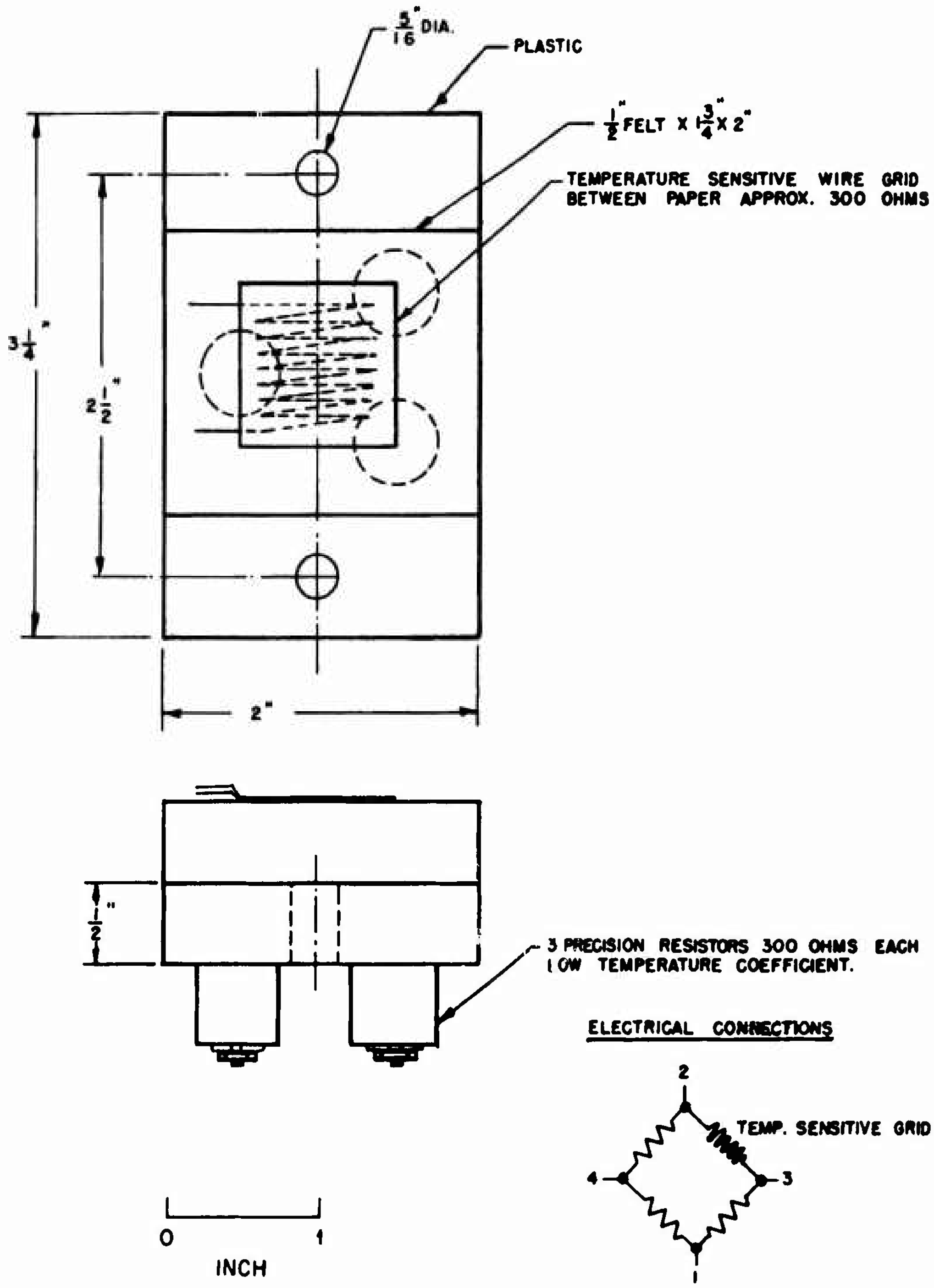


Fig. A.60 Mechanical and Electrical Details of the Resistance-wire Wall-temperature Gauge

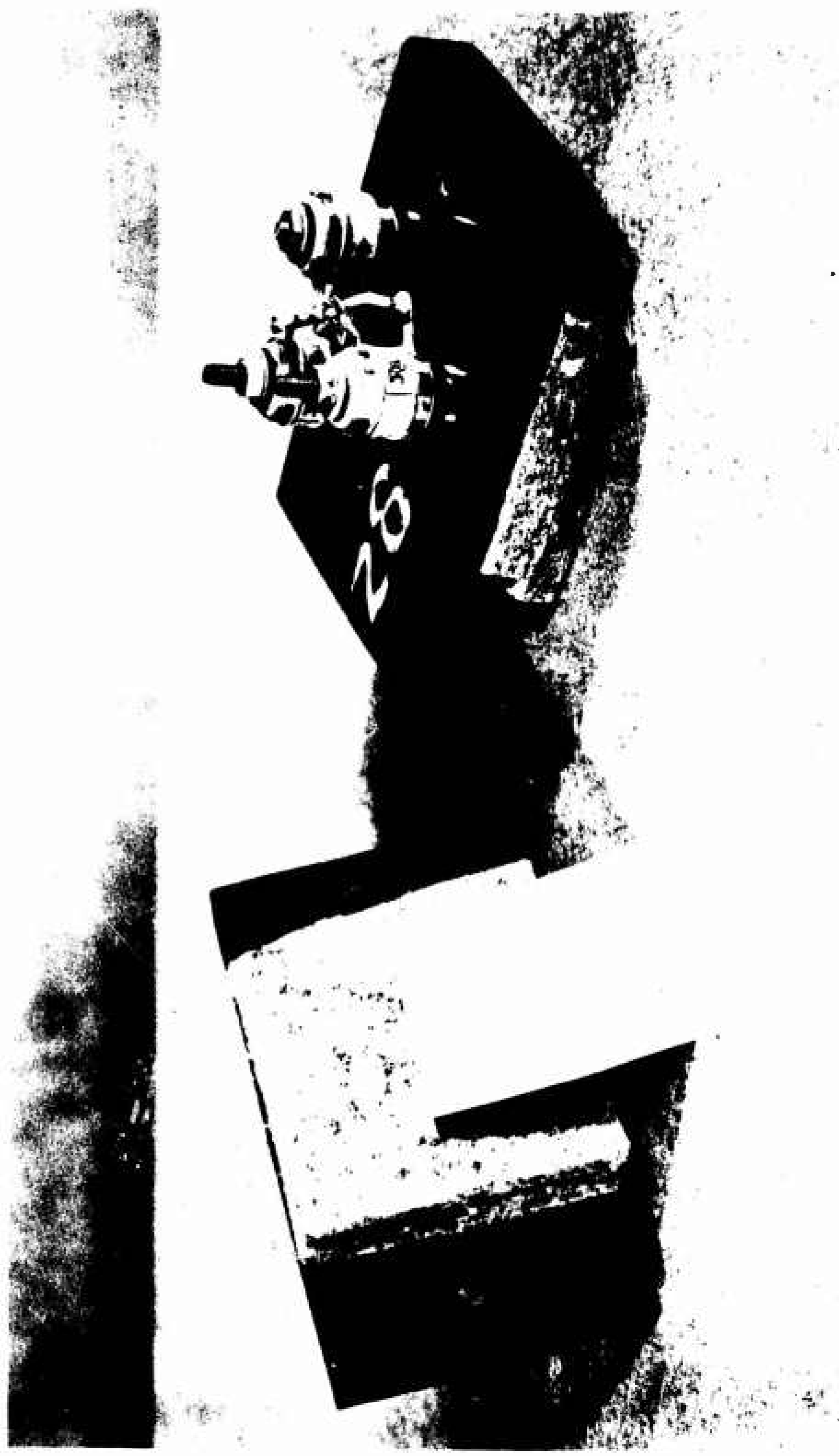
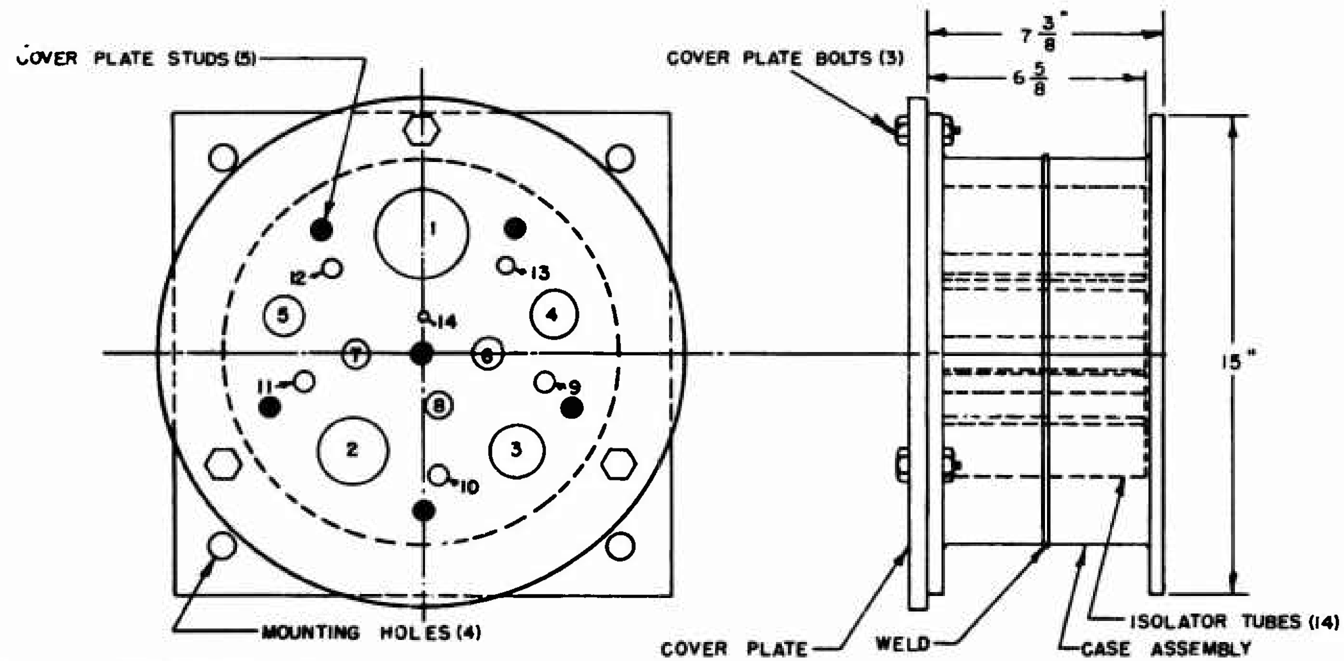
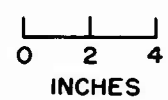


Fig. A.61 Resistance-wire Wall-temperature Gauges (Two), One Showing Active Element Lying against Felt Backing, the Other Showing Fixed Resistance Bridge Elements Attached to Back



BLAST HOLES			
HOLE NO.	HOLE DIA.	HOLE NO.	HOLE DIA.
1	3.00	8	.625
2	2.40	9	.500
3	1.92	10	.404
4	1.54	11	.323
5	1.24	12	.257
6	.984	13	.2055
7	.781	14	.166



FOIL BLAST GAGE ASSEMBLY

Fig. A.62 Foil-rupture Gauge Indicating Gauge Hole Numbering and Diameters, As Well As Other Mechanical Details

Fig. A.63 Modified Foil-rupture Gauge Ready for Assembling with 0.001-in. Aluminum Foil

Fig. A.64 Modified Foil-rupture Gauge Assembled and Loaded with 0.001-in. Aluminum Foil

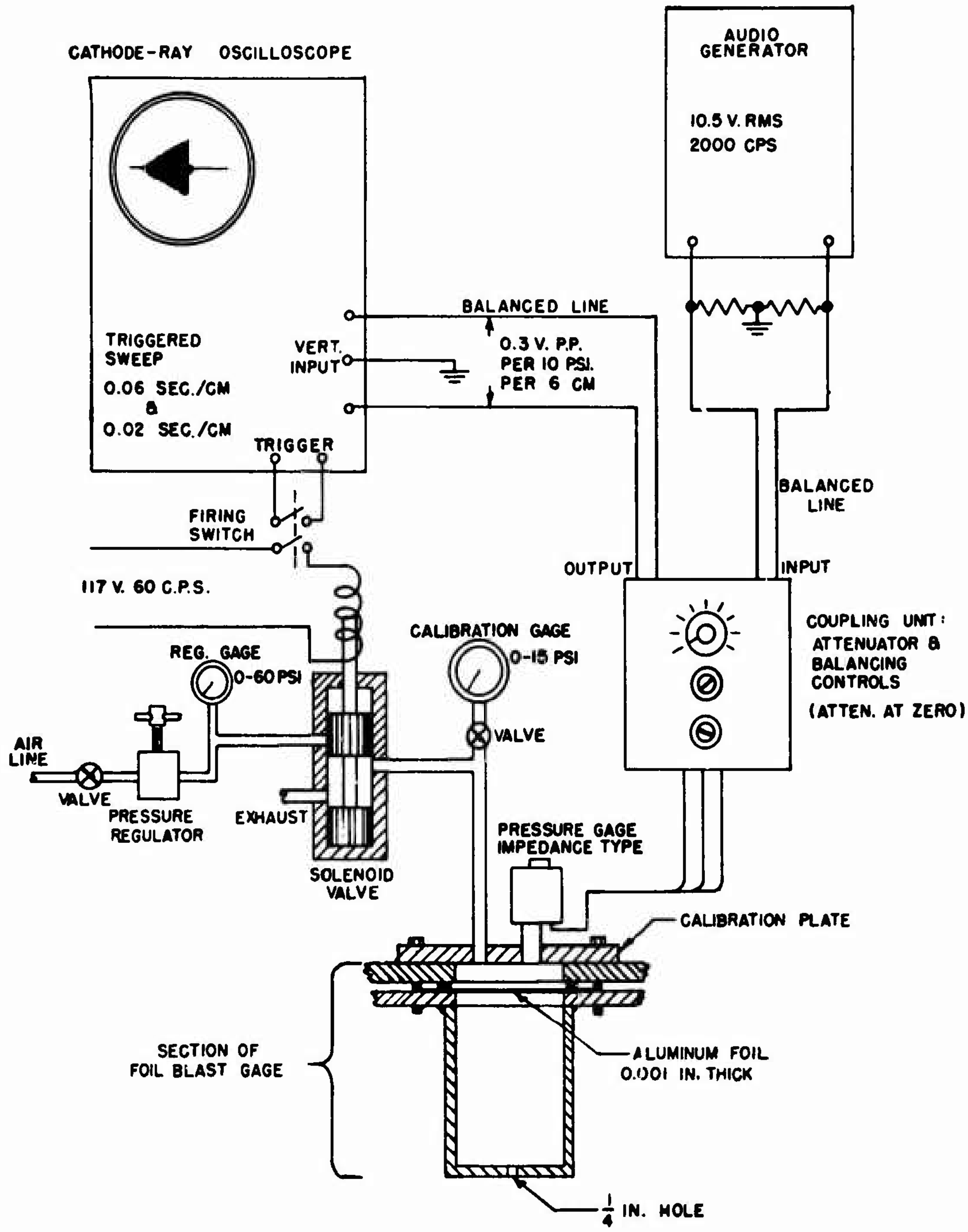


Fig. A.65 Test Arrangement Used for Determining Calibration Data on Modified Foil-rupture Gauge

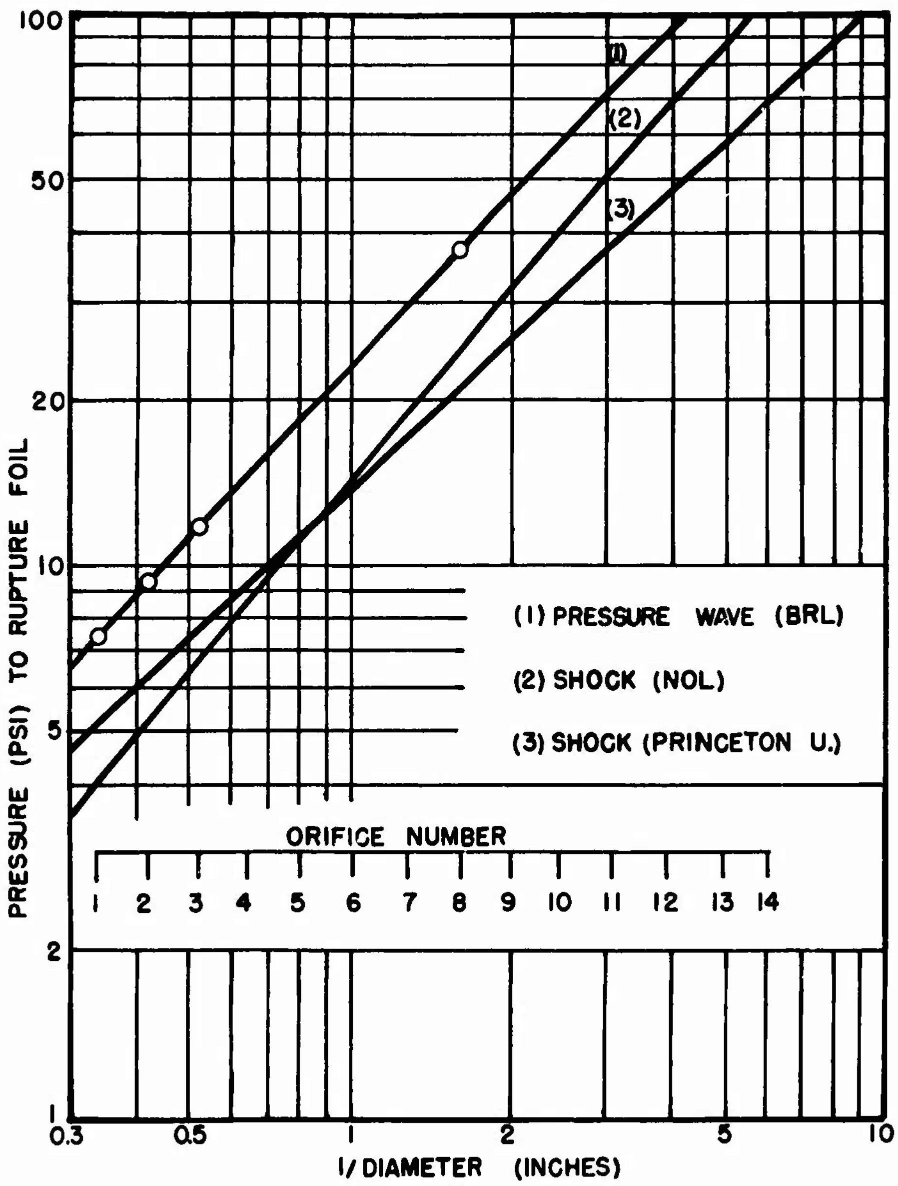


Fig. A.66 Calibration Data for Foil-rupture Gauge Using 0.001-in. Aluminum Foil. Curves 2 and 3 are reproduced here from Sandstone Reports (see text, Sec. A.3.11).

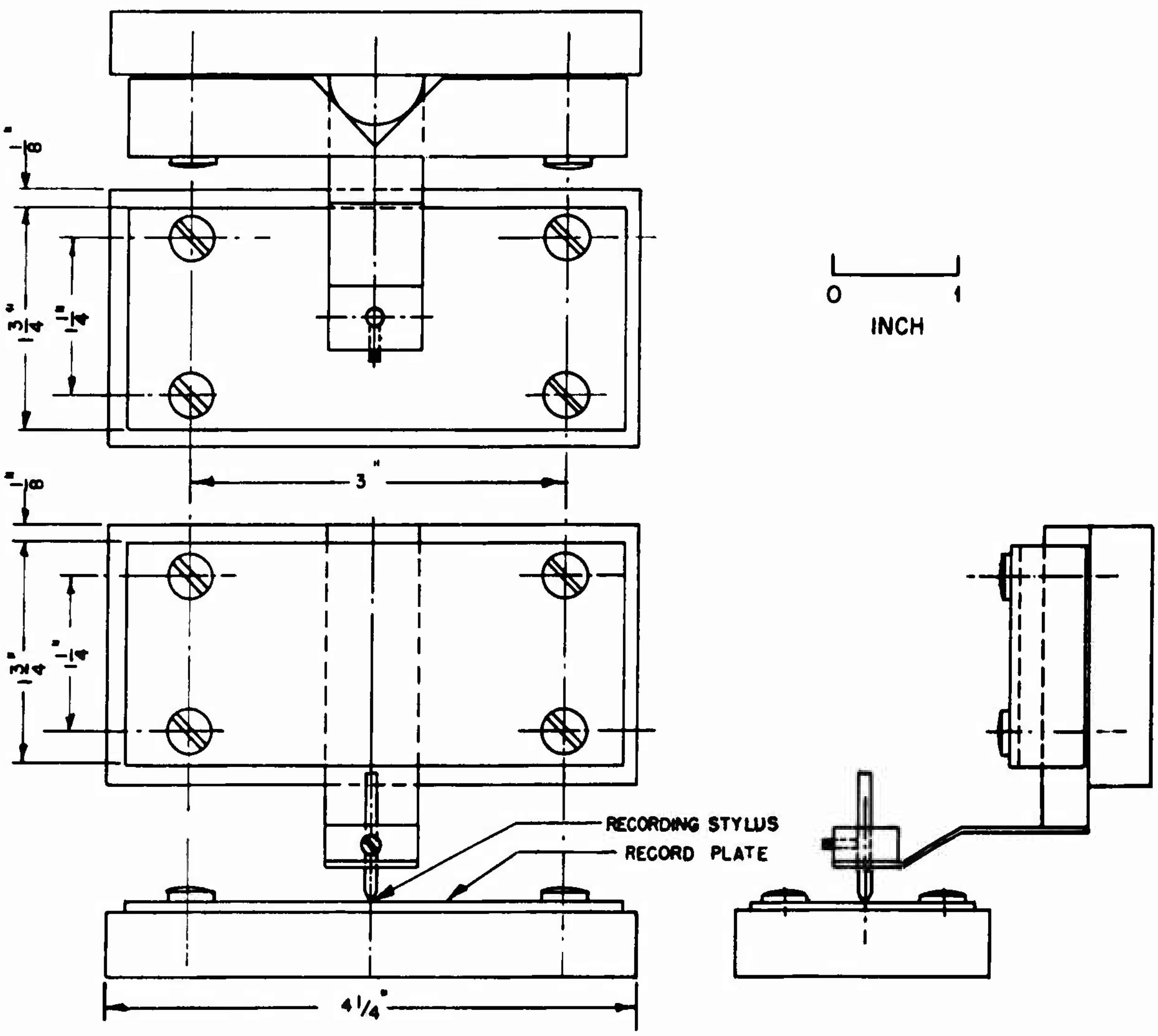


Fig. A.67 Scratch Gauge Assembly Details

Appendix B

Details of Test (Instrumentation) Results

In this appendix are presented the actual data furnished by the test instrumentation within the vehicles. Data which represent time-integrated results (gamma dosage, neutron flux, etc.) are given in tabular form. Time-variable data which were so instrumented are presented in graphical form. The order of presentation will, in general, follow the outline of Chap. 2.

B.1 NUCLEAR RADIATION

Total gamma radiation dosages are presented in the form of iso-dosage plots (lines of equal total gamma dosage) in Figs. B.2 to B.11. Figure B.1 is included to show the location and numbering system for the dosimeter data given in tabular form.

In order to obtain a quantitative idea of the standard deviation of an individual film badge (a deviation arising from random orientation and limitations in density readings), a control packet consisting of three badges tied together was placed in each vehicle. Three samples are insufficient to determine a realistic value for the standard deviation, but if the assumption is made that the percentage error is independent of the total density reading, the reading for each sample of a packet of three can be multiplied by a constant to raise or lower its value to some arbitrary level. This assumption was used with the arbitrary level chosen as the average of the two samples in vehicle 6312 (head-on exposure at 500 yd) and the constants of multiplication determined by the ratio of this average to the average of the three samples in each of the other vehicles. The standard deviation thus determined was found to be ±8 per cent of the individual reading. This value agrees well with the accuracies given by the Bureau of Standards; so it was assumed that the effect of random orientation was of a higher order than the inaccuracies incurred in the density readings. The actual sample readings are given in the Data Summary Sheets (Tables B.1 to B.10).

The effect of neutron-induced activity in the lead shielding of the film badge was not considered. However, the differences in readings of the shielded and unshielded radiophotoluminescent dosimeter samples did not indicate a regular variation in readings as a function of range; so the neutron-induced activity would appear to be a second-order effect. Tests made on the shielded radiophotoluminescent dosimeters (NRL) indicated energy independence for this dosimeter from 0.1 to 10 Mev.

The total integrated dosage, averaged from three or more sample readings, is given for each crew position in Figs. 5.2 to 5.6.

B.2 ACCELERATION AND DISPLACEMENT DATA

The acceleration-time data are shown in Figs. B.14 to B.51 as indicated in the Data Summary Sheets. Where possible, the velocity-time curves have been obtained by integrating the suitable acceleration-time curves. These data are presented in graphical form.

Certain comments are relevant to the significance and interpretation of the acceleration-time curves obtained for the various vehicles. The primary purpose for installing the accelerometers was to determine the effects of vehicle motion upon crew personnel rather than acceleration information per se. It was originally intended that the accelerations be time-inte-

TABLE B.1 DATA SUMMARY, SIDE-EXPOSED TANK, RANGE 500 YD
(Position 6311, Tank No. 883)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens $\times 10^3$	See Fig. B.1 for specific location of numbered badges
No. 1		60.0	
2		69.0	
3		14.7	This vehicle lost its turret between 0.4 and 0.8 sec after zero time. As a result, some badges were exposed to radiation without benefit of armor shielding.
4		19.4	
5		18.3	
6		10.0	
7		14.2	
8		16.4	
9		19.0	
10		16.5	
11		12.6	
12		17.7	
13		11.1	
14		19.1	
15		17.8	
16		18.6	
17		23.2	
18		Missing	
19		Missing	
20		Missing	

TABLE B.1 (Continued)

Item	Source of Data	Data	Remarks
Wall-temperature gauges	Ballistic Research Laboratories	None	Instrumentation in turret was destroyed
Rupture gauge (peak over-pressure)	Ballistic Research Laboratories	37 – 47 psi	See Appendix A for discussion of calibration
Scratch gauge	Ballistic Research Laboratories	None obtained	Turret left vehicle
ERA accelerometers	Ballistic Research Laboratories	Figs. B.14 to B.18	See Fig. A.27 for location of specific accelerometers
1V′			
1T			
3L			In turret
3T			In turret

TABLE B.2 DATA SUMMARY, HEAD-EXPOSED TANK, RANGE 500 YD
(Position 6312, Tank No. 063)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens × 10^3	See Fig. B.1 for locations
No. 1		11.3	
2		Missing	
3		12.5	
4		12.7	
5		13.6	
6		9.1	
7		19.9	
8		13.0	
9		14.9	
10		15.0	
11		13.6	
12		14.8	
13		14.4	
14		23.6	
15		22.8	
16		25.0	
17		11.8	
18		18.0	
19		8.2	
20		9.2	

TABLE B.2 (Continued)

Item	Source of Data	Data	Remarks
21		7.3	
22		9.3	
23		8.8	
24		9.9	
25		6.6	
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens × 10^3	See Fig. B.1 for locations; see Table B.1 for remarks on shielding
26a		19.5	
26b		Missing	
27		17.0	
28		6.3	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations; see Remarks, Table B.1
6		>425	
8		>425	
14		>425	
16		>425	
20		>425	
25		>425	
Temperature-sensitive paints	Ballistic Research Laboratories	No indicated temperature rise on interior tank wall	External samples were removed by blast wave, minimum sensitivity (interior samples) 150°F

TABLE B.2 (Continued)

Item	Source of Data	Data	Remarks
Wall-temperature gauges	Ballistic Research Laboratories	Maximum rise less than 20°C	Data questionable because of zero shift in the equipment
Rupture gauge (peak overpressure)	Ballistic Research Laboratories	7–9 psi	See Appendix A for discussion of calibration
Scratch gauge	Ballistic Research Laboratories	None obtained	Mounting destroyed by blast
ERA accelerometers	Ballistic Research Laboratories		See Fig. A.27 for locations
1L		None	Insensitive element
1V		See Figs. B.19 to B.22	
2V			
2T			
Film badge control, sample No.	Bureau of Standards	Roentgens $\times 10^3$	These samples were located in the tank bustle and tied together (in a random manner) in a single packet. The purpose was to obtain some indication of data scatter for a random badge orientation.
1		7.3	
2		Missing	
3		7.3	

TABLE B.3 DATA SUMMARY, SIDE-EXPOSED TANK, RANGE 750 YD
(Position 6321, Tank No. 954)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens $\times 10^3$	See Fig. B.1 for locations
No. 1		0.76	
2		1.1	
3		1.1	
4		1.3	
5		1.5	
6		1.3	
7		1.0	
8		1.9	
9		1.9	
10		1.9	
11		Missing	
12		1.9	
13		Missing	
14		1.5	
15		2.1	
16		2.0	
17		1.0	
18		1.9	
19		1.1	
20		1.1	
21		0.80	
22		1.0	
23		1.2	
24		1.3	
25		1.3	

TABLE B.3 (Continued)

Item	Source of Data	Data	Remarks
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens $\times 10^3$	See Fig. B.1 for locations; see Table B.1 for remarks on shielding
26a		3.5	
26b		4.0	
27		2.1	
28		1.12	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations; see Remarks, Table B.1
6		>425	
8		>425	
14		>425	
16		>425	
20		>425	
25		>425	
Radiation monitors (recording)	Ballistic Research Laboratories	See Fig. 5.7	
Radiation monitor (telemetering)	Bureau of Aeronautics	See Fig. 5.7	
Phantoms	Bureau of Medicine	Roentgens $\times 10^2$	No results as yet because of calibration difficulties. No. 2 is located in commander's position. No. 1 is in driver's position.
1			
2			

TABLE B.3 (Continued)

Item	Source of Data	Data	Remarks
Temperature-sensitive paints	Ballistic Research Laboratories	No indicated temperature rise on interior tank wall	External samples were removed by blast wave, minimum sensitivity (interior sample) 150°F
Wall-temperature gauges	Ballistic Research Laboratories	No indicated temperature rise	
Air-temperature gauges	Ballistic Research Laboratories	None	Apparent malfunction of element
Scratch gauge	Ballistic Research Laboratories	None	Gauge destroyed by blast
Rupture gauge	Ballistic Research Laboratories	Overpressure (peak) 7–9 psi	
Air-pressure gauges	Ballistic Research Laboratories	See Fig. B.23	
ERA accelerometers 1T 1V	Ballistic Research Laboratories	None	See Fig. A.27 for locations. Instruments were fired before zero time.
Wiancko accelerometers 1; 3–6	Ballistic Research Laboratories	See Figs. B.24 to B.30	See Fig. A.21 for locations.

TABLE B.4 DATA SUMMARY, HEAD-EXPOSED TANK, RANGE 750, YD
(Position 6322, Tank No. 257)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens × 10^3	See Fig. B.1 for badge locations
No. 1		1.6	
2		1.5	
3		1.7	
4		1.7	
5		1.6	
6		2.2	
7		2.5	
8		2.1	
9		1.9	
10		2.2	
11		1.6	
12		1.5	
13		2.1	
14		3.5	
15		4.0	
16		3.2	
17		1.5	
18		2.4	
19		1.1	
20		1.4	
21		1.4	
22		1.3	
23		1.5	
24		1.1	
25		1.2	

TABLE B.4 (Continued)

Item	Source of Data	Data	Remarks
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens × 10^3	See Fig. B.1 for locations; see Table B.1 for remarks on shielding
26a		2.5	
26b		2.65	
27		2.8	
28		1.05	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations
6		>425	
8		>425	
14		>425	
16		>425	
20		>425	
25		>425	
Phantoms	Bureau of Medicine		Data delayed because of calibration difficulties
1, driver			
2, commander			
Neutron indicators	Los Alamos Scientific Laboratory	See Fig. 5.8	
1, driver			Slow neutrons
2, driver			Fast neutrons
3, commander			Slow neutrons
4, commander			Fast neutrons

TABLE B.4 (Continued)

Item	Source of Data	Data	Remarks
Temperature-sensitive paints	Ballistic Research Laboratories	No apparent interior wall temperature rise	External samples removed by blast wave, minimum sensitivity (interior sample) 150°F
Rupture gauge	Ballistic Research Laboratories	Overpressure (peak) <7 psi	
ERA accelerometers 1L 1V	Ballistic Research Laboratories	See Figs. B.31 to B.33	See Fig. A.27 for accelerometer locations
Film badge control, sample No.	Bureau of Standards	Roentgens $\times 10^3$	See remarks on this item in Table B.2
1		2.6	
2		2.3	
3		2.0	

TABLE B.5 DATA SUMMARY, TAIL-EXPOSED TANK, RANGE 750 YD
(Position 6323, Tank No. 120)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens × 10^3	See Fig. B.1 for locations
No. 1		0.80	
2		Missing	
3		Missing	
4		Missing	
5		1.1	
6		1.0	
7		Missing	
8		0.90	
9		1.0	
10		1.0	
11		1.0	
12		0.87	
13		Missing	
14		Missing	
15		1.6	
16		Missing	
17		Missing	
18		1.1	
19		0.74	
20		0.70	
21		0.72	
22		0.80	
23		0.80	
24		0.70	
25		0.62	

TABLE B.5 (Continued)

Item	Source of Data	Data	Remarks
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens $\times 10^3$	See Fig. B.1 for locations; see Table B.1 for remarks on shielding
26a		2.2	
26b		2.1	
27		1.43	
28		1.0	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations; see Remarks, Table B.1
6		>425	
8		>425	
14		Missing	
16		Missing	
20		>425	
25		>425	
Phantom	Bureau of Medicine	None	Driver's position; see Remarks, Table B.3
1			
Temperature-sensitive paints	Ballistic Research Laboratories	None	Exterior samples removed by blast wave, minimum sensitivity (interior sample), 150°F
Wall-temperature gauge	Ballistic Research Laboratories	None	Malfunction of recording equipment

TABLE B.5 (Continued)

Item	Source of Data	Data	Remarks
Air-temperature gauges 1 2	Ballistic Research Laboratories	None	Malfunction of recording equipment
Scratch gauge	Ballistic Research Laboratories	None	Damaged by overturning of vehicle
Rupture gauge	Ballistic Research Laboratories	Overpressure 7–9 psi	
Air-pressure gauges 1 2	Ballistic Research Laboratories	None	Malfunction of recording equipment
ERA accelerometers	Ballistic Research Laboratories	None	Equipment fired ahead of time
Wiancko accelerometers	Ballistic Research Laboratories	None	Malfunction of recording equipment

TABLE B.6 DATA SUMMARY, SIDE-EXPOSED TANK, RANGE 1000 YD
(Position 6331, Tank No. 117)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens $\times 10^2$	See Fig. B.1 for locations
No. 1		1.9	
2		4.6	
3		3.2	
4		3.7	
5		5.1	
6		5.1	
7		3.7	
8		8.5	
9		8.3	
10		7.6	
11		7.0	
12		7.2	
13		7.0	
14		5.3	
15		6.3	
16		7.2	
17		5.0	
18		7.8	
19		3.5	
20		2.6	
21		2.4	
22		2.1	
23		3.4	
24		5.1	
25		5.0	

TABLE B.6 (Continued)

Item	Source of Data	Data	Remarks
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens $\times 10^2$	See Fig. B.1 for locations; see Table B.1 for remarks
26a		5.0	
26b		6.4	
27		8.25	
28		Missing	
Film badge control, sample No.	Bureau of Standards	Roentgens $\times 10^2$	See Remarks, Table B.2, for this item
1		7.7	
2		7.6	
3		8.0	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations
6		350	
8		>425	
14		>425	
16		>425	
20		350	
25		>425	
Neutron indicators 1–4	Los Alamos Scientific Laboratory	See Fig. 5.8	See Remarks, Table B.4, for locations

TABLE B.6 (Continued)

Item	Source of Data	Data	Remarks
Phantoms 1 2	Bureau of Medicine	None	See Remarks, Table B.3
Radiation Monitors 1, recording 2, telemetering	Ballistic Research Laboratories, Bureau of Aeronautics	None	Recorder did not function Equipment in aircraft did not function
Temperature-sensitive paints	Ballistic Research Laboratories	No indicated temperature rise inside vehicle No readable data on external samples	Minimum sensitivity (interior sample), 150°F Minimum sensitivity (exterior samples), 1100°F
Wall temperature	Ballistic Research Laboratories	None	Recorder did not function
Air temperature	Ballistic Research Laboratories	None	Recorder did not function
Air pressure	Ballistic Research Laboratories	None	Recorder did not function
ERA accelerometers 1T 1V	Ballistic Research Laboratories	See Figs. B.34 to B.37	See Fig. A.27 for location
Wiancko accelerometers	Ballistic Research Laboratories	None	Recorder did not function

TABLE B.7 DATA SUMMARY, HEAD-EXPOSED TANK, RANGE 1000 YD
(Position 6332, Tank No. 440)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens × 10^2	See Fig. B.1 for locations
No. 1		3.5	
2		2.5	
3		3.5	
4		3.7	
5		3.6	
6		6.0	
7		4.6	
8		4.4	
9		4.5	
10		3.3	
11		3.0	
12		3.3	
13		2.6	
14		5.6	
15		10	
16		7.6	
17		4.4	
18		5.8	
19		2.9	
20		3.5	
21		3.7	
22		3.1	
23		3.5	
24		2.7	
25		2.3	

TABLE B.7 (Continued)

Item	Source of Data	Data	Remarks
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens $\times 10^2$	See Fig. B.1 for locations; see Table B.1 for remarks on shielding
26a		5.6	
26b		7.2	
27		6.3	
28		2.1	
Film badge control, sample No.	Bureau of Standards	Roentgens $\times 10^2$	See Table B.2 for remarks on this item
1		6.3	
2		5.7	
3		6.5	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations
6		>425	
8		>425	
14		>425	
16		>425	
20		350	
25		285	
Temperature-sensitive paints	Ballistic Research Laboratories	No rise in interior wall temperature	Exterior samples removed by blast, minimum sensitive temperature (interior), 150°F
Wall temperature	Ballistic Research Laboratories	No rise	Recorded data

TABLE B.7 (Continued)

Item	Source of Data	Data	Remarks
Air temperature 1 2 3	Ballistic Research Laboratories	See Figs. B.38 and B.39	No. 1 gives conditions in fighting compartment. No. 2 gives conditions in driver's compartment. No. 3 is D.C. recording in fighting compartment.
Air pressure 1 2	Ballistic Research Laboratories	See Fig. B.40	No. 1 for fighting compartment No. 2 for driver's compartment
ERA accelerometers 1L 1V	Ballistic Research Laboratories	None	There was no time base for these data; hence the records were not reduced
Wiancko accelerometers 1–3; 5–6	Ballistic Research Laboratories	See Figs. B.41 to B.47	See Fig. A.21 for locations

TABLE B.8 DATA SUMMARY, SIDE-EXPOSED TANK, RANGE 1233 YD
(Position 6341, Tank No. 872)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens $\times 10^2$	See Fig. B.1 for locations
No. 1		0.52	
2		0.55	
3		0.75	
4		0.81	
5		1.7	
6		1.7	
7		0.70	
8		2.9	
9		2.7	
10		2.7	
11		2.5	
12		2.7	
13		3.0	
14		1.8	
15		3.0	
16		2.8	
17		0.73	
18		2.5	
19		1.4	
20		0.70	
21		0.83	
22		0.78	
23		1.4	
24		1.4	
25		1.9	

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TABLE B.8 (Continued)

Item	Source of Data	Data	Remarks
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens $\times 10^2$	See Fig. B.1 for locations; see Table B.1 for remarks on shielding
26a		1.5	
26b		1.5	
27		1.7	
28		0.25	
Film badge control, sample No.	Bureau of Standards	Roentgens $\times 10^2$	See Table B.2 for remarks on this item
1		3.5	
2		3.5	
3		3.4	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations
6		200	
8		375	
14		215	
16		310	
20		60	
25		215	
Phantoms	Bureau of Medicine	None	See Table B.3 for locations and remarks on this item
1			
2			

TABLE B.8 (Continued)

Item	Source of Data	Data	Remarks
Temperature-sensitive paints	Ballistic Research Laboratories	No readable rise on exterior samples	Minimum sensitive value of 1100°F
Wall temperature	Ballistic Research Laboratories	No rise	Recorded data
Air temperature	Ballistic Research Laboratories	See Fig. B.48	Fighting compartment
Air pressure	Ballistic Research Laboratories	See Fig. B.49	
1			No. 1 in fighting compartment
2			No. 2 in driver's compartment
Wiancko accelerometer 3	Ballistic Research Laboratories	None	No apparent motion

TABLE B.9 DATA SUMMARY, TAIL-EXPOSED TANK, RANGE 1233 YD
(Position 6343, Tank No. 424)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens × 10^2	See Fig. B.1 for locations
No. 1		0.50	
2		1.2	
3		1.0	
4		0.56	
5		0.82	
6		1.1	
7		0.40	
8		1.7	
9		1.4	
10		1.6	
11		2.1	
12		1.5	
13		1.4	
14		2.0	
15		1.5	
16		1.8	
17		0.72	
18		1.2	
19		0.31	
20		0.27	
21		0.20	
22		0.25	
23		0.24	
24		0.18	
25		0.19	

TABLE B.9 (Continued)

Item	Source of Data	Data	Remarks
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens $\times 10^2$	See Fig. B.1 for locations; see Table B.1 for remarks on shielding
26a		1.45	
26b		1.65	
27		0.52	
28		<0.25	
Film badge control, sample No.	Bureau of Standards	Roentgens $\times 10^2$	See Table B.2 for remarks on this item
1		0.90	
2		1.2	
3		1.3	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations
6		170	
8		250	
14		250	
16		250	
20		40	
25		30	
Phantom	Bureau of Medicine	None	See remarks on this item in Table B.3
1			

TABLE B.9 (Continued)

Item	Source of Data	Data	Remarks
Temperature-sensitive paints	Ballistic Research Laboratories	No apparent temperature rise in external samples	Minimum sensitivity for these samples was 1100°F
Air temperature	Ballistic Research Laboratories	See Fig. B.48	Located in fighting compartment
1			
Air pressure	Ballistic Research Laboratories	See Fig. B.50	
1			No. 1 in fighting compartment
2			No. 2 in driver's compartment
Wiancko accelerometers	Ballistic Research Laboratories	See Figs. B.51 and B.52	See Fig. A.21 for location
1			
2			

TABLE B.10 DATA SUMMARY, SIDE-EXPOSED TANK, RANGE 1400 YD
(Position 6351, Tank No. 418)

Item	Source of Data	Data	Remarks
Film badges	Bureau of Standards	Roentgens $\times 10^2$	See Fig. B.1 for locations
No. 1		0.20	
2		Missing	Sample lost
3		0.35	
4		0.51	
5		0.92	
6		Missing	Sample lost
7		Missing	Sample lost
8		1.7	
9		1.6	
10		1.5	
11		1.5	
12		Missing	Sample lost
13		1.1	
14		0.45	
15		1.4	
16		1.6	
17		Missing	Sample lost
18		Missing	Sample lost
19		Missing	Sample lost
20		0.32	

TABLE B.10 (Continued)

Item	Source of Data	Data	Remarks
21		0.33	
22		Missing	Sample lost
23		Missing	Sample lost
24		1.0	
25		0.38	
Radiophotoluminescent dosimeters	Naval Research Laboratory	Roentgens $\times 10^2$	See Fig. B.1 for locations; see Table B.1 for remarks on shielding
26a		0.88	
26b		0.25	
27		0.88	
28		<0.25	
Exterior total gamma, dosage No.	Bureau of Standards and Naval Research Laboratory	Roentgens $\times 10^2$	Samples 1 to 9 are film badge measurements. Samples 10 to 19 are radiophotoluminescent dosimeter measurements. All samples were placed in a canvas bag and placed on the track of the vehicle. The only shield was that of the canvas bag. Average of exterior data is 625 r.
1		7.2	
2		6.9	
3		6.0	
4		5.7	
5		5.2	
6		6.3	
7		5.9	
8		6.0	
9		5.9	
10		7.0	

TABLE B.10 (Continued)

Item	Source of Data	Data	Remarks
11		6.6	
12		6.1	
13		6.0	
14		6.0	
15		4.5	
16		6.5	
17		6.4	
18		6.8	
19		8.0	
Film badge control, sample No.	Bureau of Standards	Roentgens $\times 10^2$	See Table B.2 for remarks on this item
1		1.9	
2		1.9	
3		1.6	
Polaroid dosimeters	Evans Signal Laboratory, Signal Corps Engineering Laboratories	Roentgens	See Fig. B.1 for locations
6		150	
8		215	
14		150	
16		190	
20		50	
25		150	
Phantoms	Bureau of Medicine	None	See remarks on this item in Table B.3
1			
2			
Temperature-sensitive paints	Ballistic Research Laboratories	No temperature rise in interior or exterior samoles	Minimum sensitivity for interior sample was 150°F. Minimum sensitivity for exterior samples was 1100°F.

grated to determine velocity- and displacement-time curves. Upon careful inspection it was found that integration of the acceleration curves would lead to no really useful data on displacements. A study of the probable errors inherent in the acceleration measuring system and the propagation of such errors upon integration showed (and was proved in practice) that velocity determinations were poor and displacement data completely erroneous. Certain portions of the accelerometer records could be analytically interpreted to correspond to certain motions of the tanks, i.e., changes in friction coefficient as the tank slides, but further interpretation appeared dangerous. The conclusion is almost inevitable that gross measurements of tank motion require a different measuring technique, one which has extremely low frequency modes of vibration.

In presenting the acceleration data, certain alterations to the raw material have been made. The high-frequency large-amplitude oscillations are of little or no importance to personnel although of considerable importance to certain items of equipment. Consequently, the high-frequency components in the records were removed, first by analytically smoothing some of the raw data and then by running the records through a filter before recording. The analytical method was used as a check on the electronic filter. The filter finally used had a linear response (±10 per cent) from 0 to 35 cps, decreasing to 10 per cent response at 65 cps. It was shown that incorporation of the filter did not significantly change time-integrated data; hence it was concluded that frequencies greater than 35 cps are of no consequence in gross motions of the tanks.

In obtaining certain of the velocity-time data, it was found necessary to stop the integration before motion of the vehicle had ceased. There were several reasons for this, the primary one being that large angular motions occurred with insufficient data to resolve the various component values. Thus the integration was stopped when it was felt that large angular motions were occurring.

Following the test exposure, careful measurements were made on tank displacements. In order to orient the displacements, it is convenient to postulate the following coordinate system:

1. Each vehicle has associated with it a right-handed cartesian coordinate system with the xy plane and the earth's surface coincident.
2. The positive x lies in a direction away from the blast, and the x axis coincides with the radius vector from the tower base through the vehicle center of gravity (projected on the xy plane).
3. The center of gravity of the vehicle (projected on the xy plane) is the origin of the coordinate system.
4. The angles ϕ, θ, and α represent positive rotations about the x, y, and z axes, respectively.
5. The radial distance from the tower base to the centers of gravity of the vehicles is specified, as well as an azimuthal angle, with zero azimuth along the north geographical meridian (positive clockwise).

The coordinate displacements are indicated in Table B.11.

The gross motions of the tanks indicated that at close ranges to the bomb it may well be impossible to predict individual vehicle motions. The size of soil particles relative to the size of the vehicle is too large and the distances moved by the vehicles too short to permit elimination, by a statistically large number of events, of very irregular variations in the coefficient of sliding friction. Further, it appears that the coefficient of sliding friction changes rapidly at some critical velocity of the tank (i.e., the tank tends to dig in if pulled at a certain velocity), and this critical velocity must differ very greatly with different soil types and with soil moisture.

In connection with the theoretical problem of predicting the sliding motion of tanks exposed to a severe blast, certain tests were carried out at the Aberdeen Proving Ground to determine the sliding friction of the medium tank. Obviously it was impossible to transport sufficient soil from the island of Engebi to perform these tests; so a local site was chosen in which the soil closely resembled that of the Eniwetok Atoll. To supplement the information obtained, a detailed soil analysis was carried out on a small sample of Eniwetok soil and compared to a similar analysis of the soil on which the tanks were tested. It is felt that such information is of sufficient general interest to be included in this report.

TABLE B.11 GROSS MOTIONS OF VEHICULAR CENTERS OF GRAVITY*

Vehicle	Orientation	Azimuth (deg)	Range (yd)	x (ft)	y (ft)	z (ft)	ϕ (deg)	θ (deg)	α (deg)
M-46, hull	Side-on	96.0	500	61.6	0	−1	−5	10	±180
turret				119.6	−5.8	−5	Unknown	Unknown	Unknown
M-26	Head-on	100.0	500	16.5	−2.1	−1	0	−5	21
M-26	Side-on	82.82	750	46.5	−1	2	15	200	−20
M-26	Head-on	80.52	750	44.6	−8.3	−1	5	−5	0
M-26	Tail-on	85.16	750	53.3	0	2	0	210	0
M-26	Side-on	95.0	1000	3.3	0	0	0	0	0
M-26	Head-on	93.0	1000	0.1	0	0	0	0	0
M-46	Side-on	82.0	1233	0	0	0	0	0	0
M-26	Tail-on	79.72	1233	0	0	0	0	0	0
M-26	Side-on	123.36	1400	0	0	0	0	0	0

*The coordinate system used in this table is explained in Sec. B.2.

The vehicles tested on the local soil (bank gravel) were the M-46 tank, 47.5 tons; the M-26 tank, 43.2 tons; and the T-34 Russian tank, 33.6 tons. The M-46 and M-26 tanks have steel-faced, rubber pad tracks, and the T-34 tank has cast-steel Russian track. The M-7 Field Dynamometer was used to measure the resistance to towing of these vehicles. Measurements were made at breakaway (force required to set the vehicle in motion) and at a road speed of 0.2 mph, towing the vehicles forward with the brakes released and with brakes locked, and towing sideways. Average values obtained were as follows:

Test Conditions	lb	lb/ton	y
	M-46		
Brakes released			
Breakaway	5,000	105.2	
Sustained	4,000	84.3	
Brakes locked			
Breakaway	68,000		0.716
Sustained	65,000		0.684
	M-26		
Brakes released			
Breakaway	6,000	138.8	
Sustained	5,000	115.7	
Brakes locked			
Breakaway	63,000		0.730
Sustained	69,000		0.683
	T-34		
Brakes released			
Breakaway	3,700	110.0	
Sustained	3,000	89.3	
Brakes locked			
Breakaway	46,000		0.683
Sustained	42,000		0.625
Sideways			
Breakaway	47,000		0.700

Results for the sideways towing of the T-34 tank indicated that the coefficient of friction (y in the table) thus obtained was the same as that for forward towing with the brakes locked. Because of this, similar tests for the M-26 and M-46 tanks were not conducted. A summary of the soil analyses is given in Table B.12. The determination of tank friction coefficients and the analyses of soil samples were carried out by the Automotive Laboratory, Development and Proof Services, Aberdeen Proving Ground.

B.3 INTERIOR PRESSURE- AND TEMPERATURE-TIME DATA

The vehicle interior pressure- and temperature-time curves for ranges of 750, 1000, and 1233 yd from ground zero are given in Figs. B.23, B.39, B.48, and B.49.

B.4 SHOCK WAVE TIME OF ARRIVAL

The time of arrival of the shock wave can be accurately determined by use of the Wiancko accelerometer records. The time interval between burst and shock arrival is known because of an excellent zero timing mark arising from the burst of radiation and a high-frequency response in the accelerometers. At each of the ranges where the Webster-Chicago recorders were operated (750, 1000, and 1233 yd), there are three or more accelerometer records, and the mean value for these records should give an excellent measure of the time of arrival.

It is interesting to note that a fitted curve through the values at 1000 and 1233 yd passing through the origin agrees very well with data obtained along the long blast line. However, the values for time of arrival at 750 and 500 yd are much closer to the data obtained along the short blast line and are strongly suggestive of a jet or similar phenomenon. From a curve fitted to the data at 1000 and 1233 yd and a second curve fitted to the data at 500 and 750 yd, it is possible to determine roughly the time-of-arrival curve and hence the peak overpressures experienced at the vehicle locations. In Figs. B.12 and B.13 are shown the time-of-arrival data and the deduced peak overpressures at the vehicle locations.

B.5 PRESENTATION OF ACCELERATION- AND VELOCITY-TIME CURVES

In presenting these data it was felt that interpretation would be simpler if the positive

TABLE B.12 SUMMARY OF ANALYSES OF BANK GRAVEL AND ENGEBI SOIL SAMPLES*

Item	Size (mm)	Engebi Sample	Bank Gravel Sample
Particle size			
Gravel, coarse	4.76–76.20	41%	21%
Gravel, fine	2.00–4.76	3%	16%
Sand, coarse	0.25–2.00	42%	34%
Sand, fine	0.05–0.25	7%	14%
Silt	0.005–0.95	4%	10%
Clay	<0.005	3%	5%
Colloids, in clay	<0.001	(1.5%)	(1.6%)
Specific gravity, true		2.72	2.68
Organic content		3200 ppm	40 ppm
Hardness test, Mohs' number		4	7
Coefficient of friction, internal		0.477	0.460
Angle of friction, $\tan^{-1}$ ratio of vertical load to horizontal resistance		25.5°	25.0°
Cohesion		0.04 psi	0.02 psi
Moisture		3.3%	0.9%

*Both soil samples failed to respond to the Atterburg plasticity test. Each soil exhibited a granular sandy structure which lacked sufficient clay binder to produce the required cohesion of a plastic soil.

direction of acceleration and velocity were chosen independent of a particular vehicle orientation. Accordingly, the curves showing accelerations and velocities indicate radial, transverse, and vertical motion. The positive sense of these motions are chosen as (1) radial, away from tower; (2) transverse, counterclockwise when viewed from above; and (3) vertical, away from surface of the earth.

Specific accelerometer identification and reference to the instrument location diagram are included in Tables B.1 to B.10.

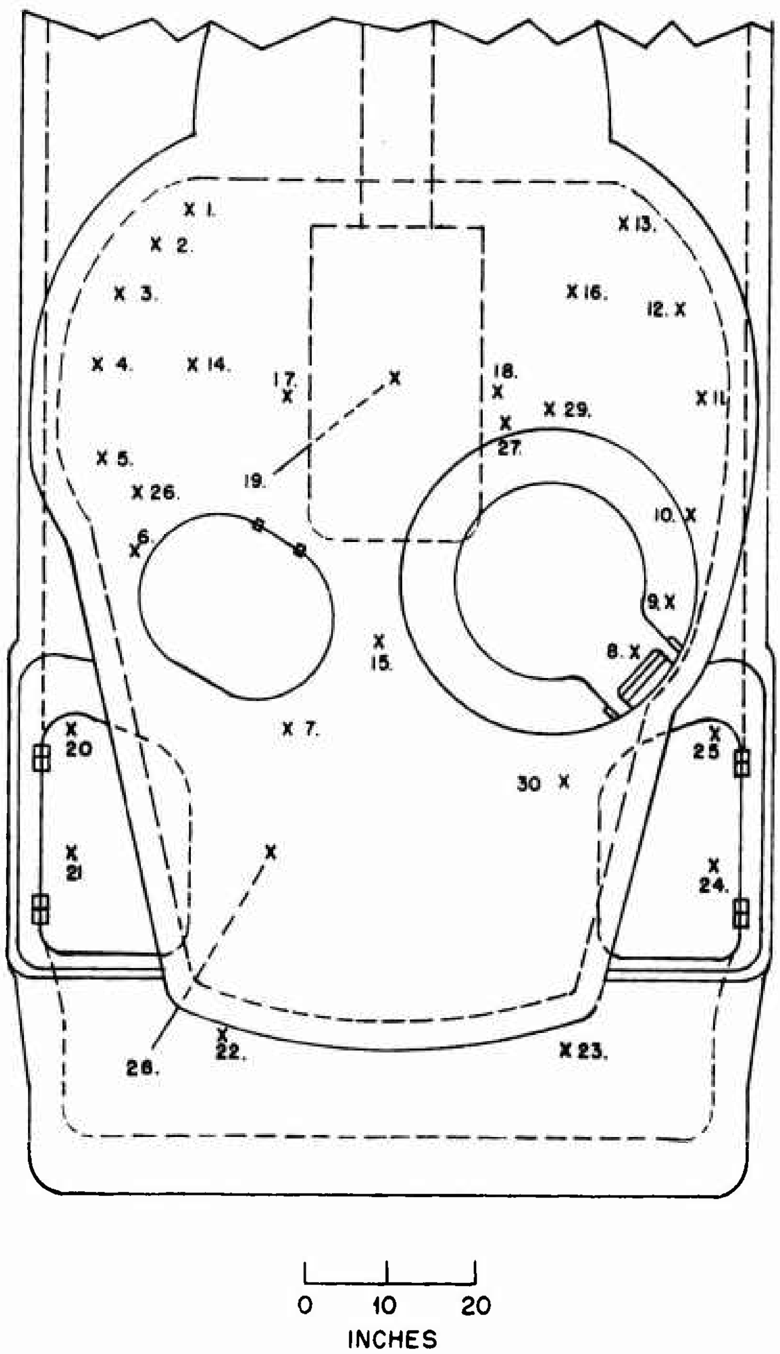

Fig. B.1 Plan View Showing Relative Thicknesses of the M-46 Medium Tank and Location of Dosimeters: 1 through 25, Film Badges and Polaroid Dosimeters; 26 through 28, Radiophotoluminescent Glass Dosimeters; 29 and 30, Neutron Flux Indicators

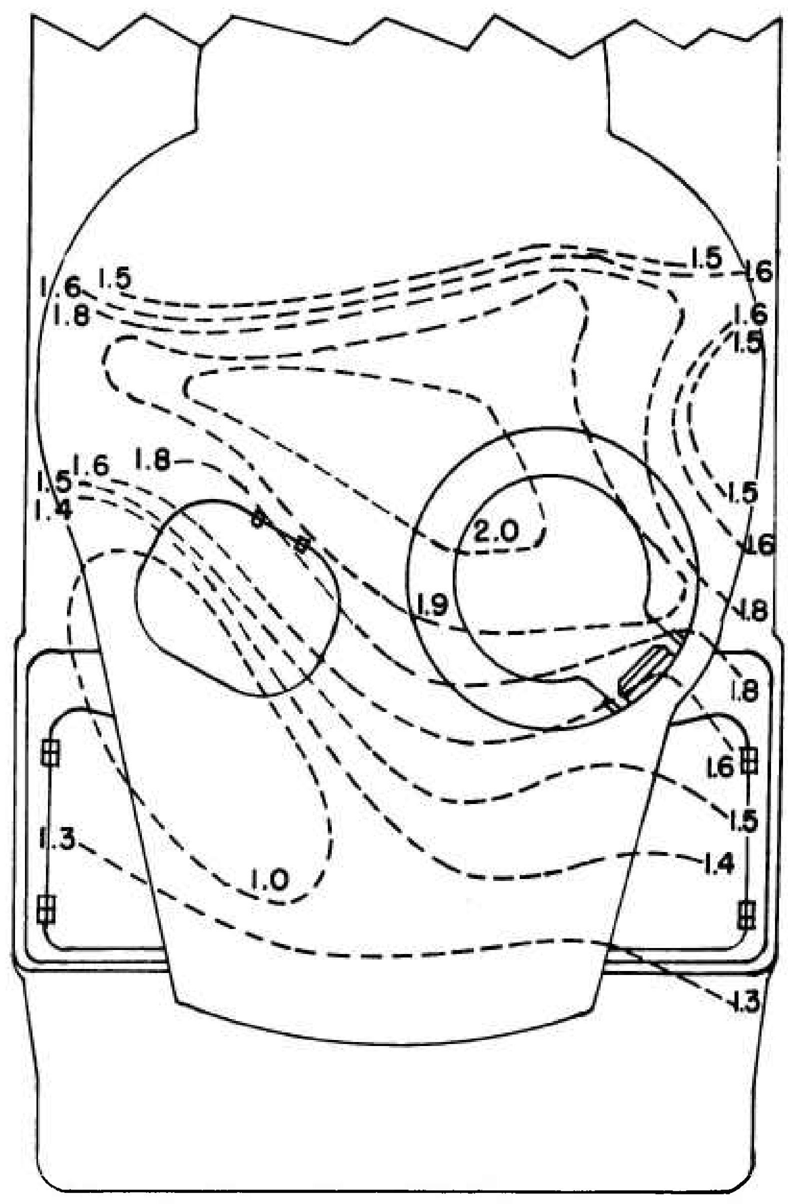

Fig. B.2 Iso-dosage Lines (Value Times 10^4 r) for Side-on Tank at 500 Yd from Ground Zero

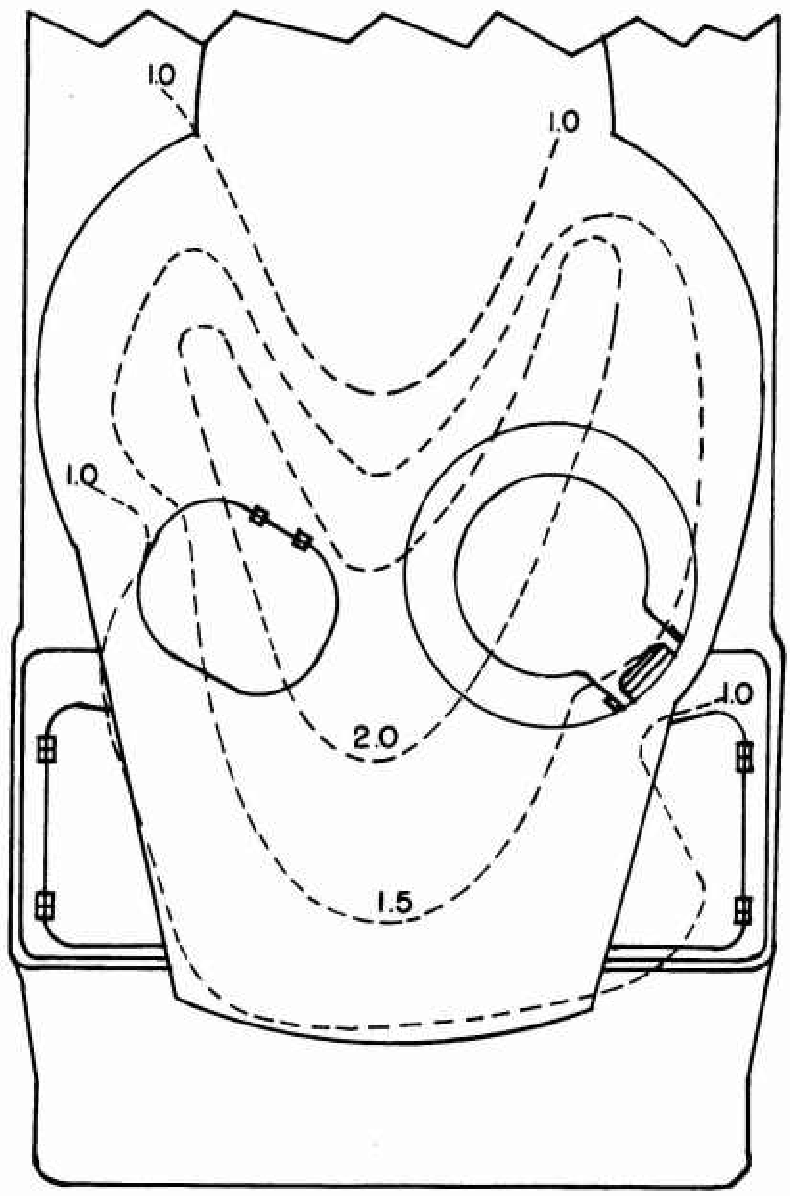

Fig. B.3 Iso-dosage Lines (Value Times 10^4 r) for Head-on Tank at 500 Yd from Ground Zero

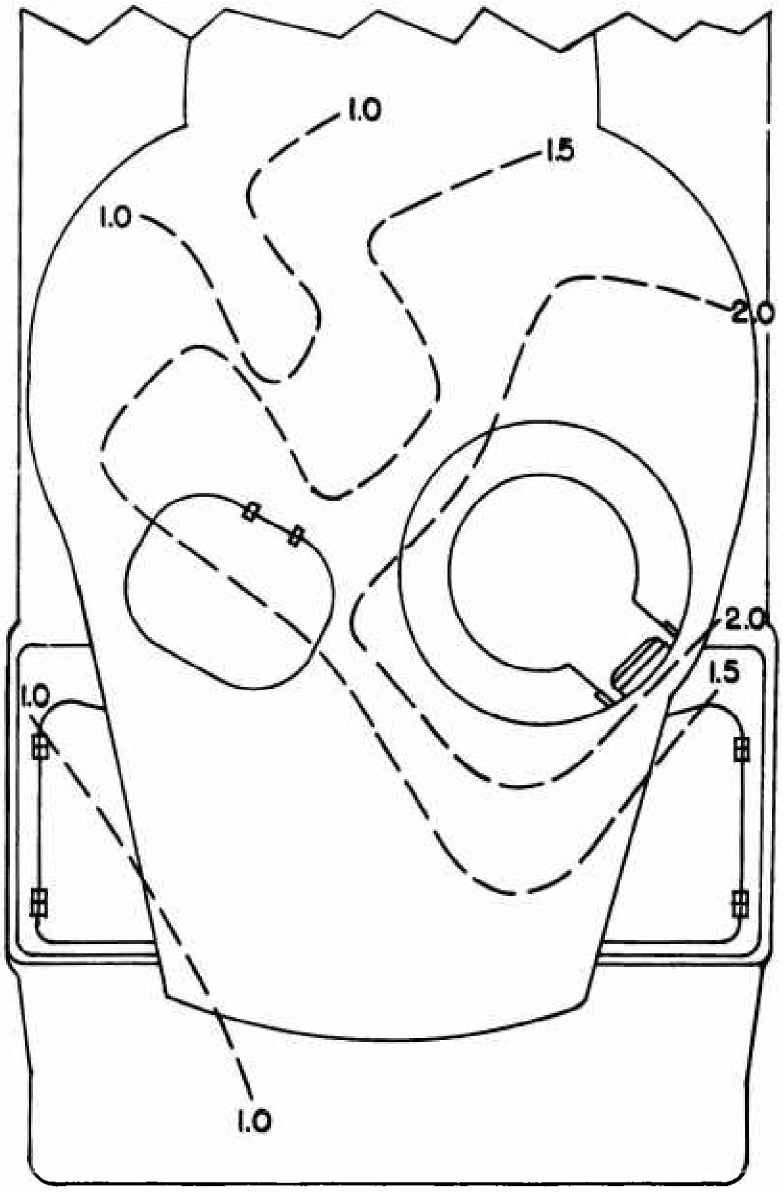

Fig. B.4 Iso-dosage Lines (Value Times 10^3 r) for Side-on Tank at 750 Yd from Ground Zero

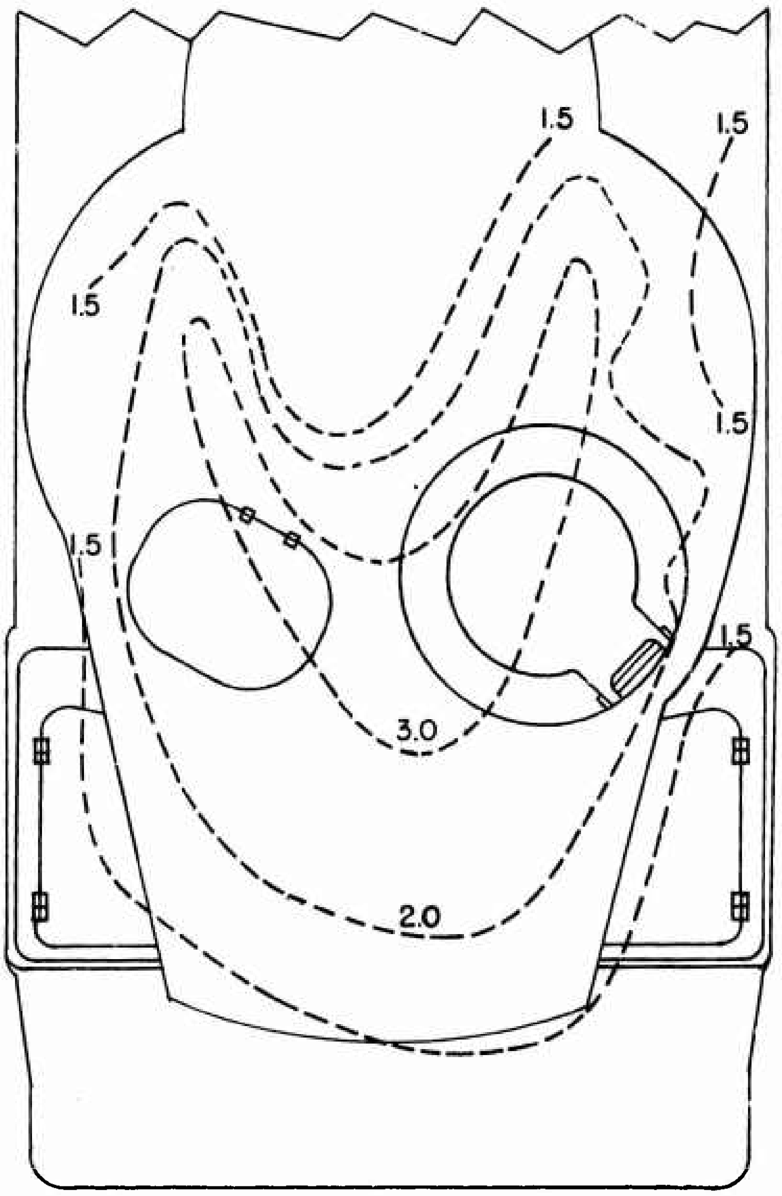

Fig. B.5 Iso-dosage Lines (Value Times 10^3 r) for Head-on Tank at 750 Yd from Ground Zero

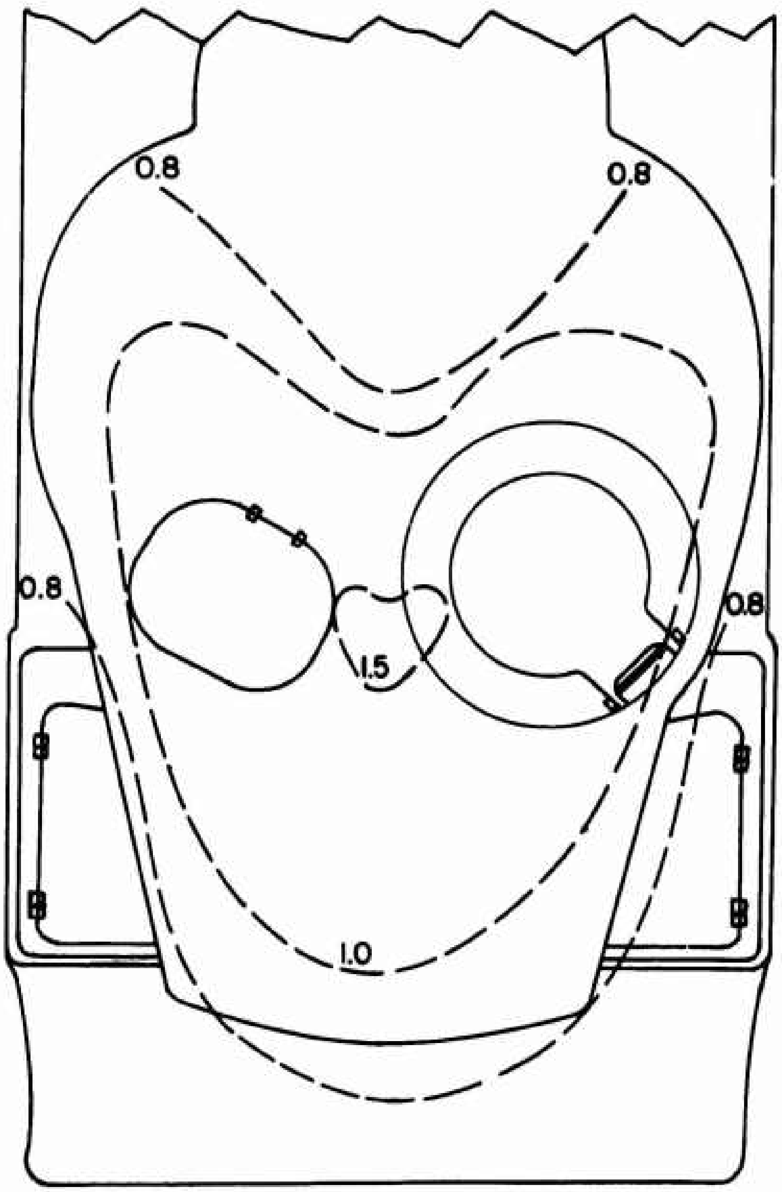

Fig. B.6 Iso-dosage Lines (Value Times 10^3 r) for Tail-on Tank at 750 Yd from Ground Zero

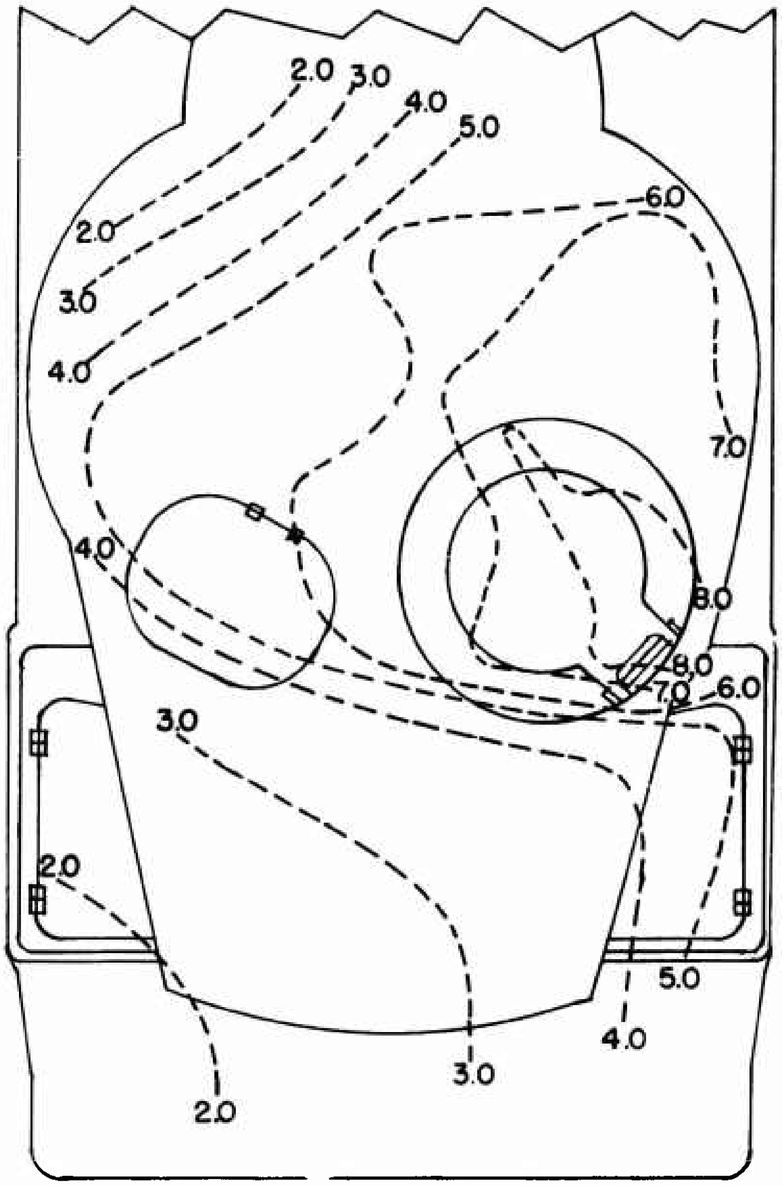

Fig. B.7 Iso-dosage Lines (Value Times 10^2 r) for Side-on Tank at 1000 Yd from Ground Zero

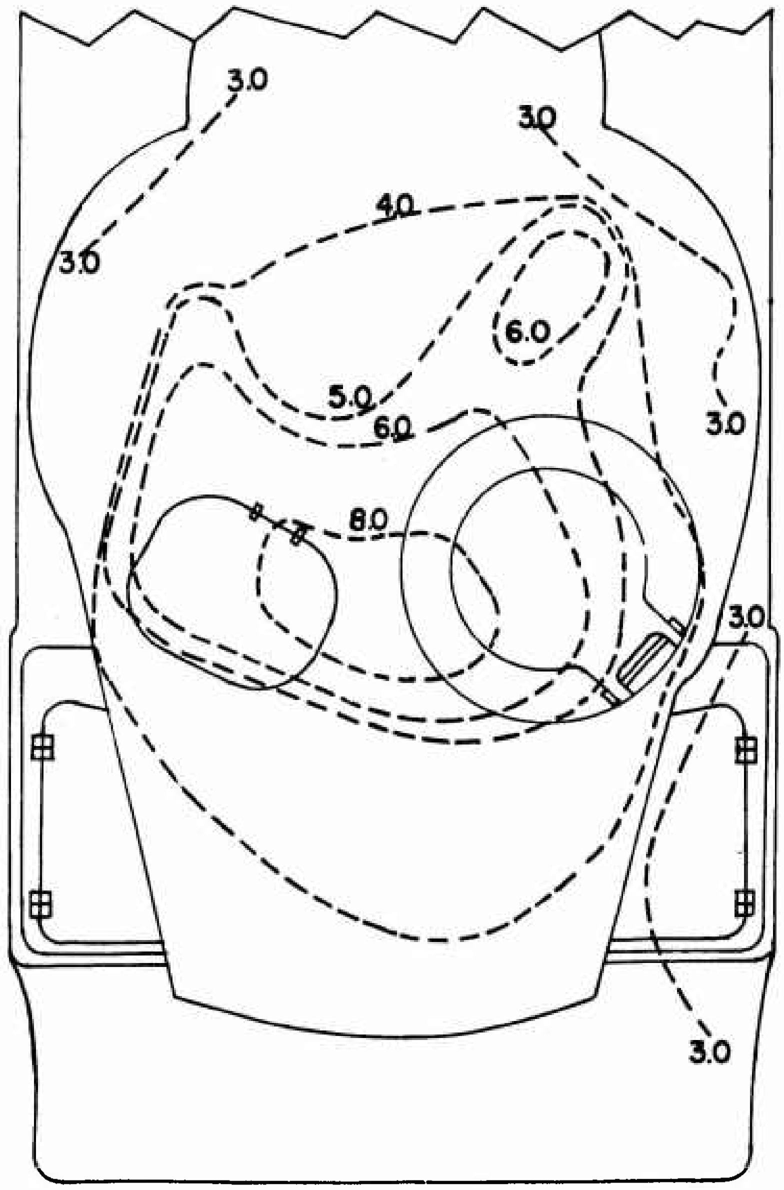

Fig. B.8 Iso-dosage Lines (Value Times 10^2 r) for Head-on Tank at 1000 Yd from Ground Zero

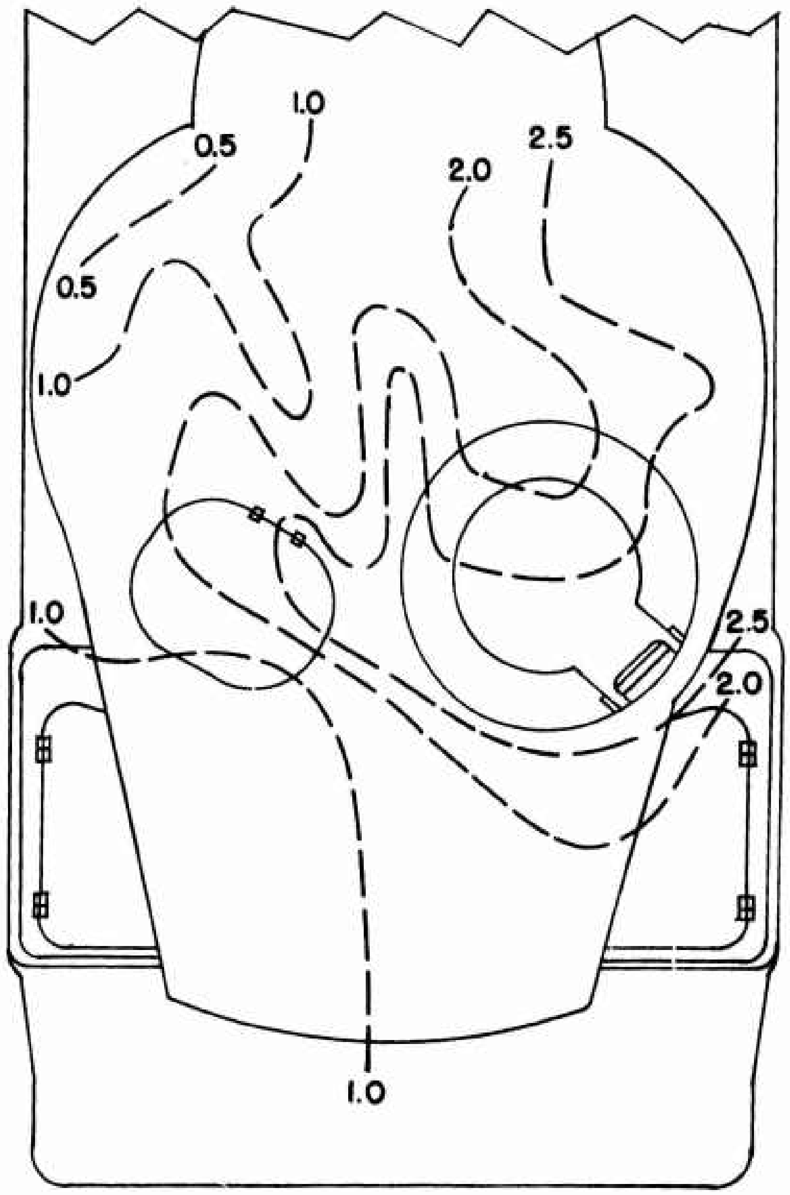

Fig. B.9 Iso-dosage Lines (Value Times 10^2 r) for Side-on Tank at 1233 Yd from Ground Zero

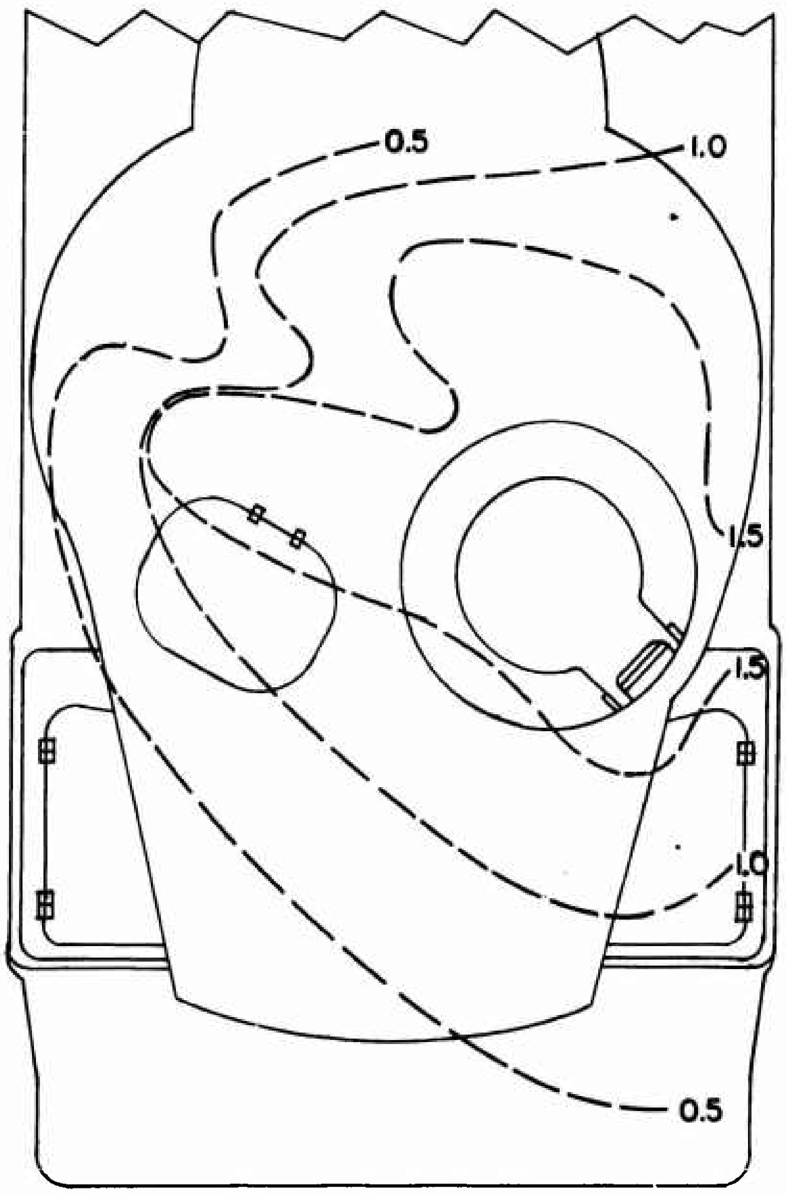

Fig. B.11 Iso-dosage Lines (Value Times 10^2 r) for Side-on Tank at 1400 Yd from Ground Zero

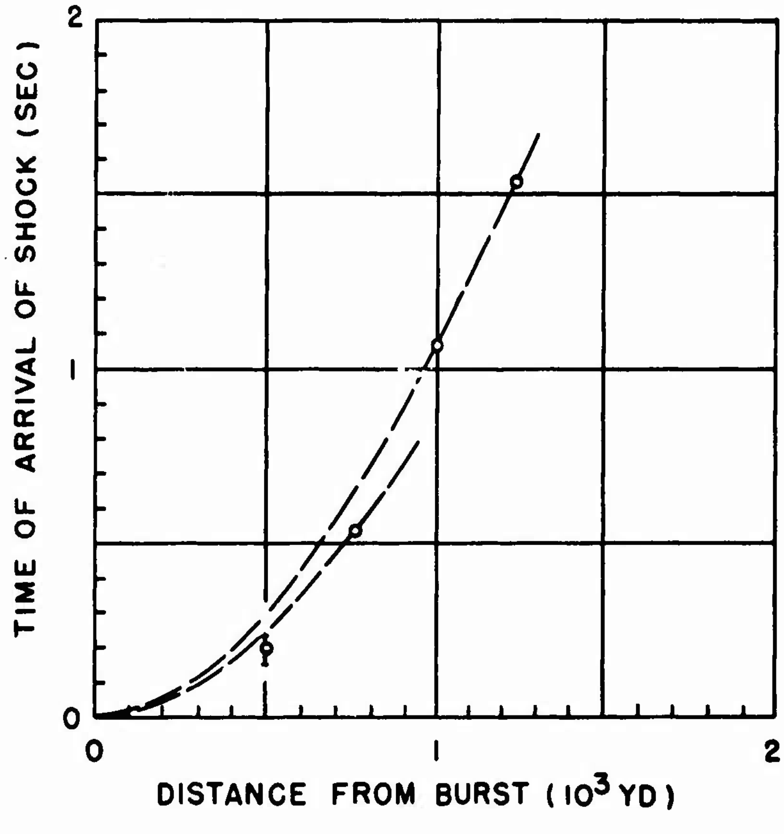

Fig. B.12 Time of Arrival of Shock at Various Distances from the Bomb

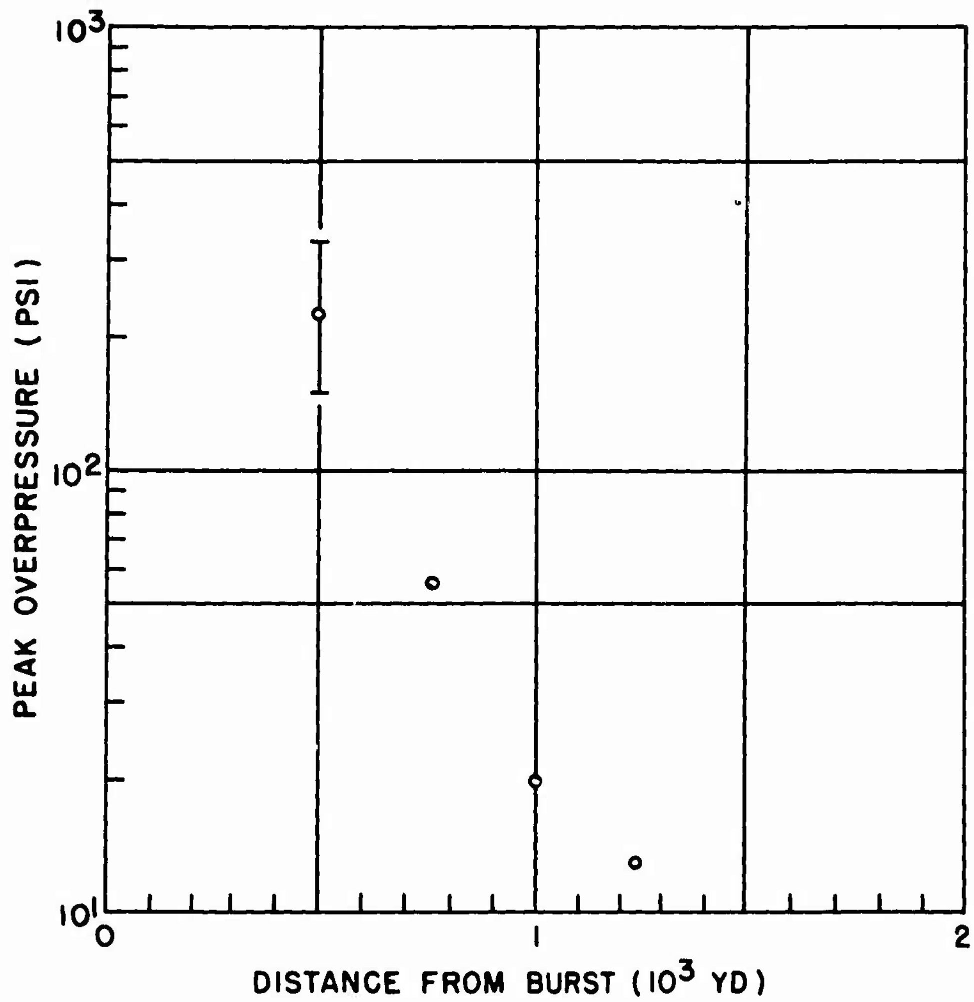

Fig. B.13 Peak Overpressure at Various Distances from the Bomb

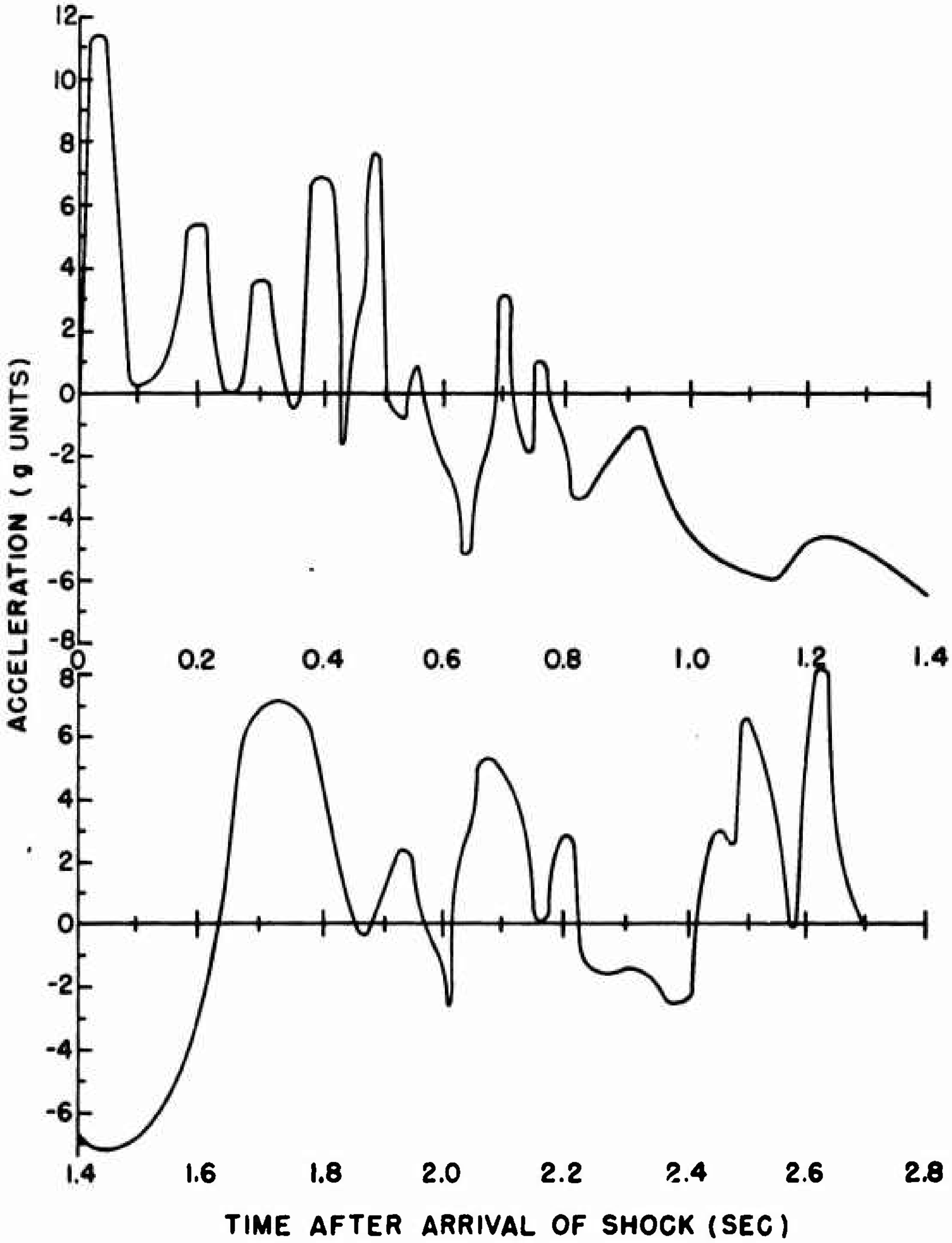

Fig. B.14 Vertical Acceleration for Side-on Tank at 500 Yd from Ground Zero (Accelerometer 1V′). Standard deviation is ±3 g.

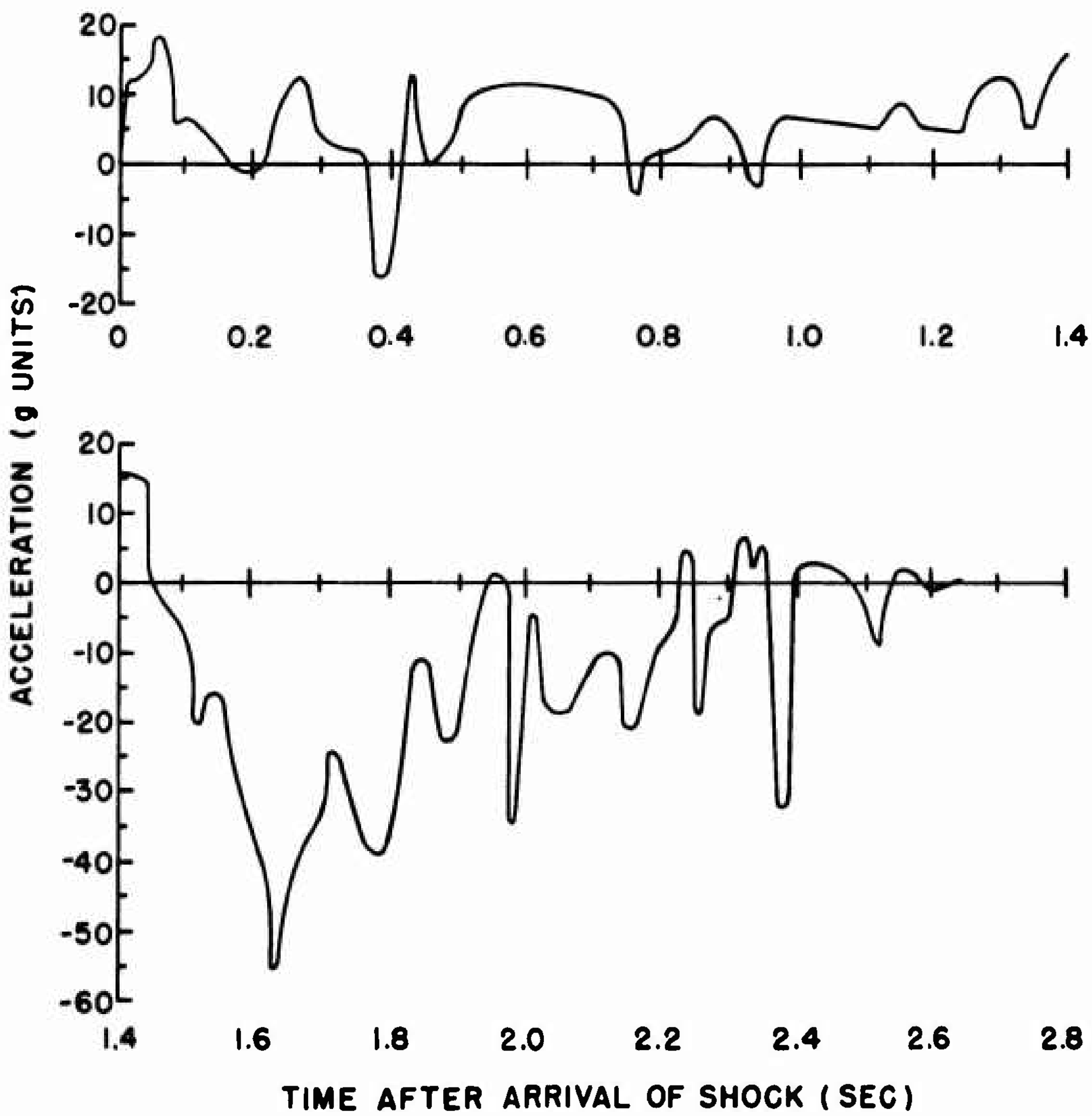

Fig. B.15 Radial Acceleration for Side-on Tank at 500 Yd from Ground Zero (Accelerometer 1T). Standard deviation is ±9 g.

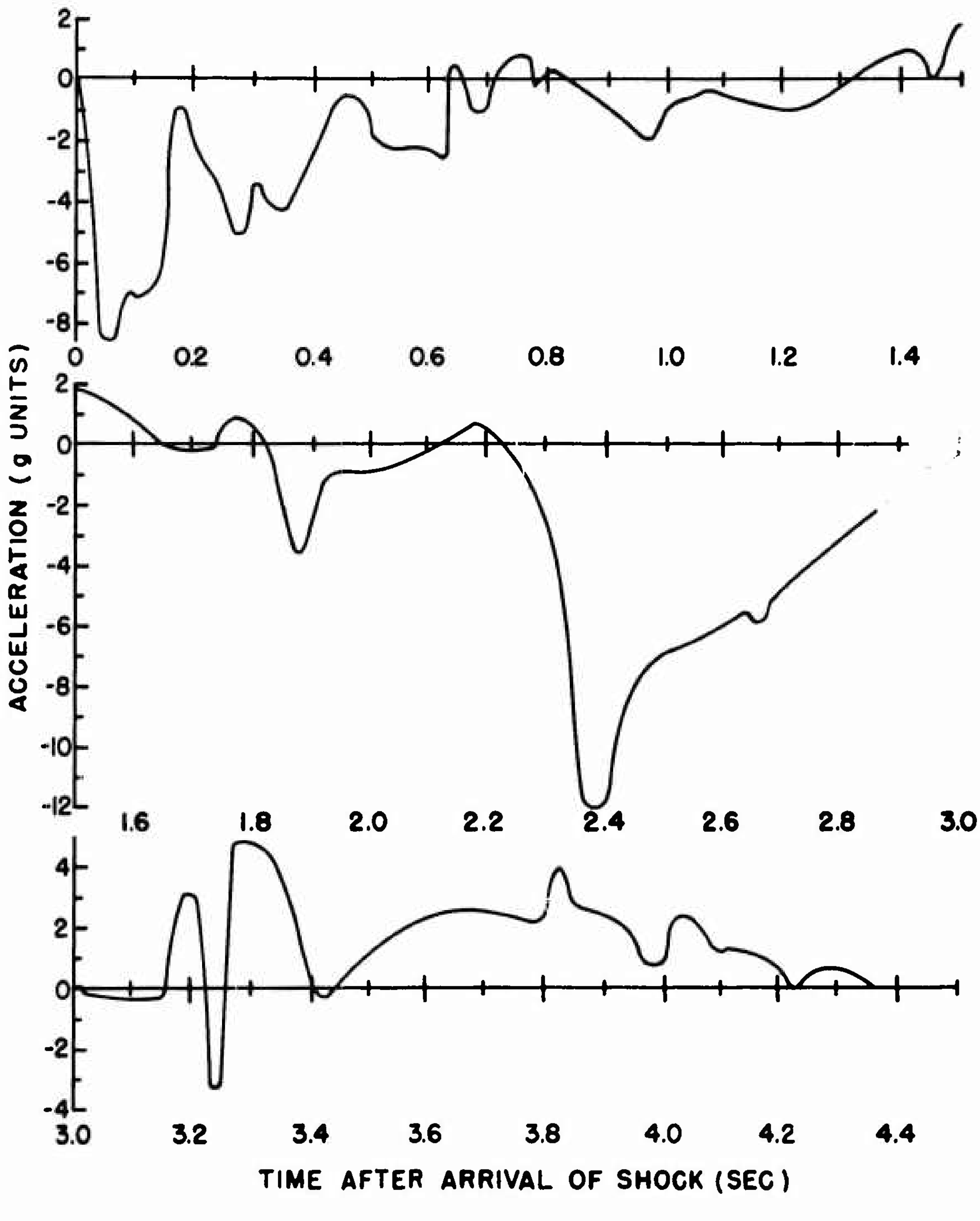

Fig. B.16 Transverse Acceleration for Side-on Tank at 500 Yd from Ground Zero (Turret, Accelerometer 3L). Standard deviation is ±1 g.

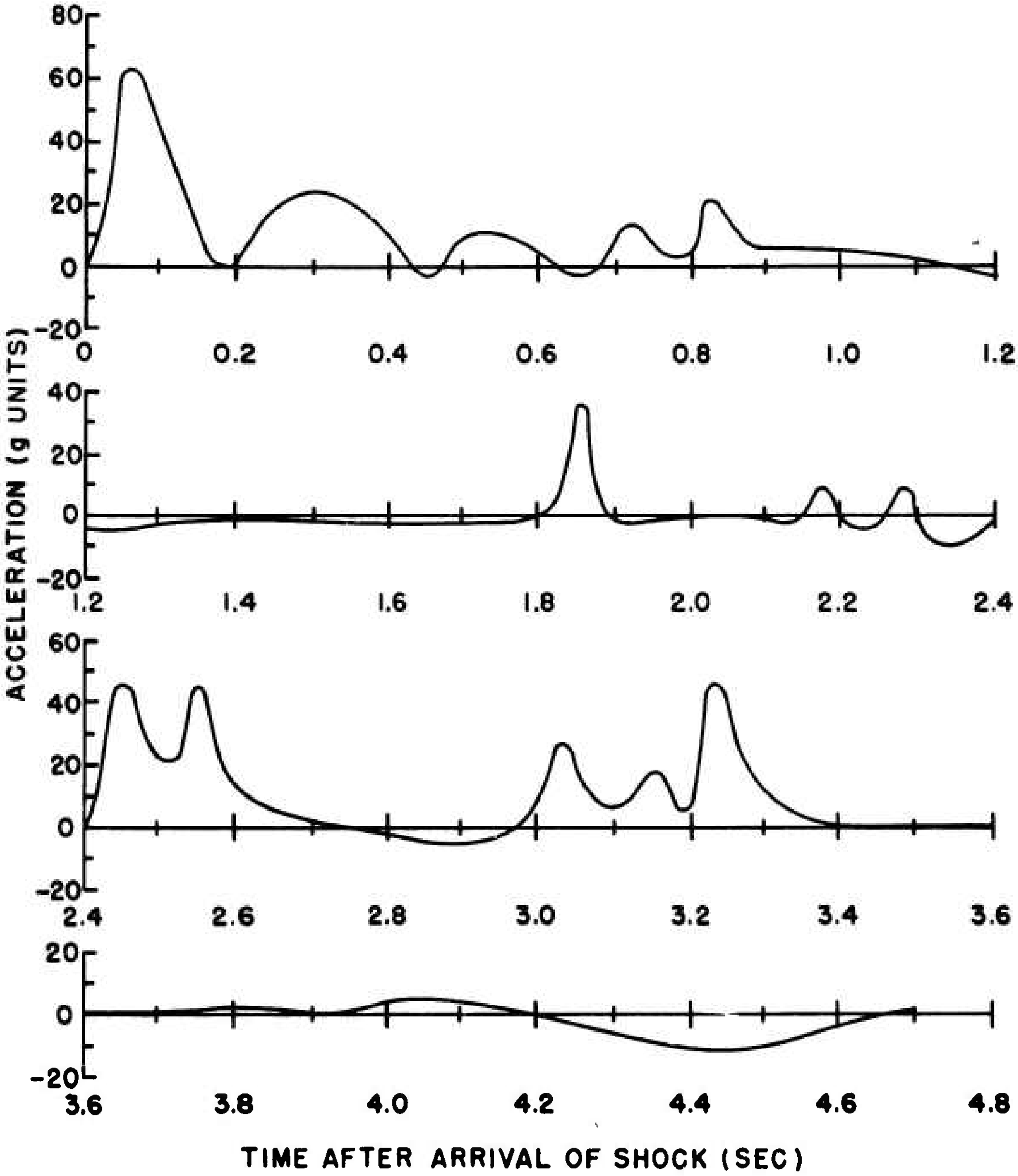

Fig. B.17 Radial Acceleration for Side-on Tank at 500 Yd from Ground Zero (Turret, Accelerometer 3T). Standard deviation is ±5 g.

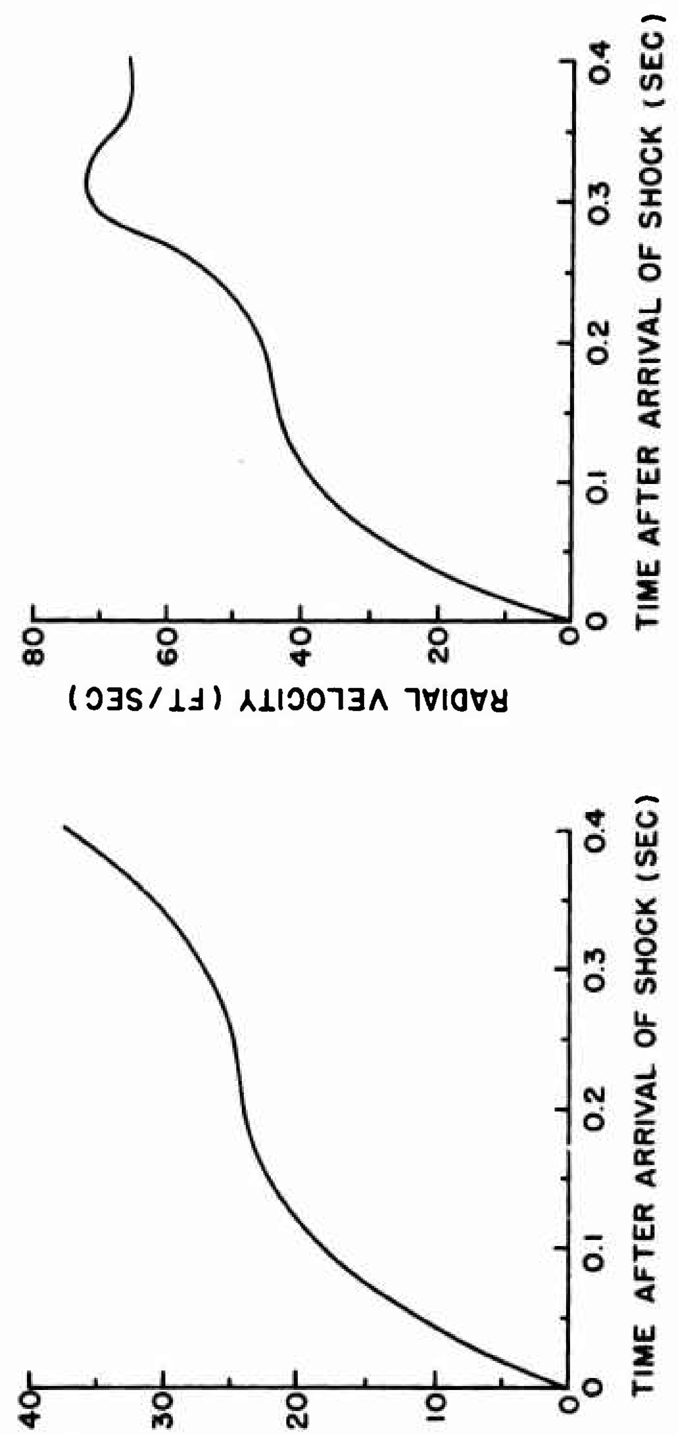

Fig. B.18 Vertical and Radial Velocities for Side-on Tank at 500 Yd from Ground Zero (Accelerometers 1V' and 1T)

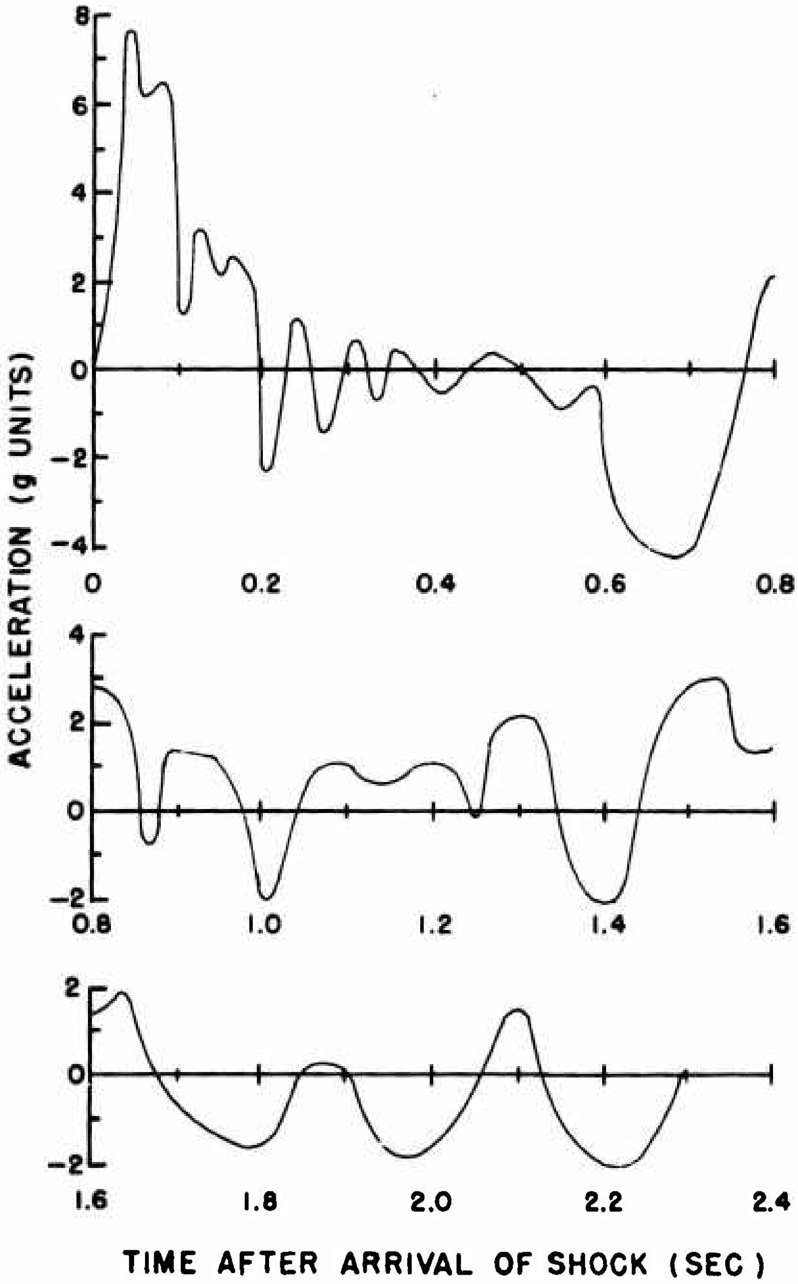

Fig. B.19 Vertical Acceleration for Head-on Tank at 500 Yd from Ground Zero (Accelerometer 1V). Standard Deviation is ±0.7 g.

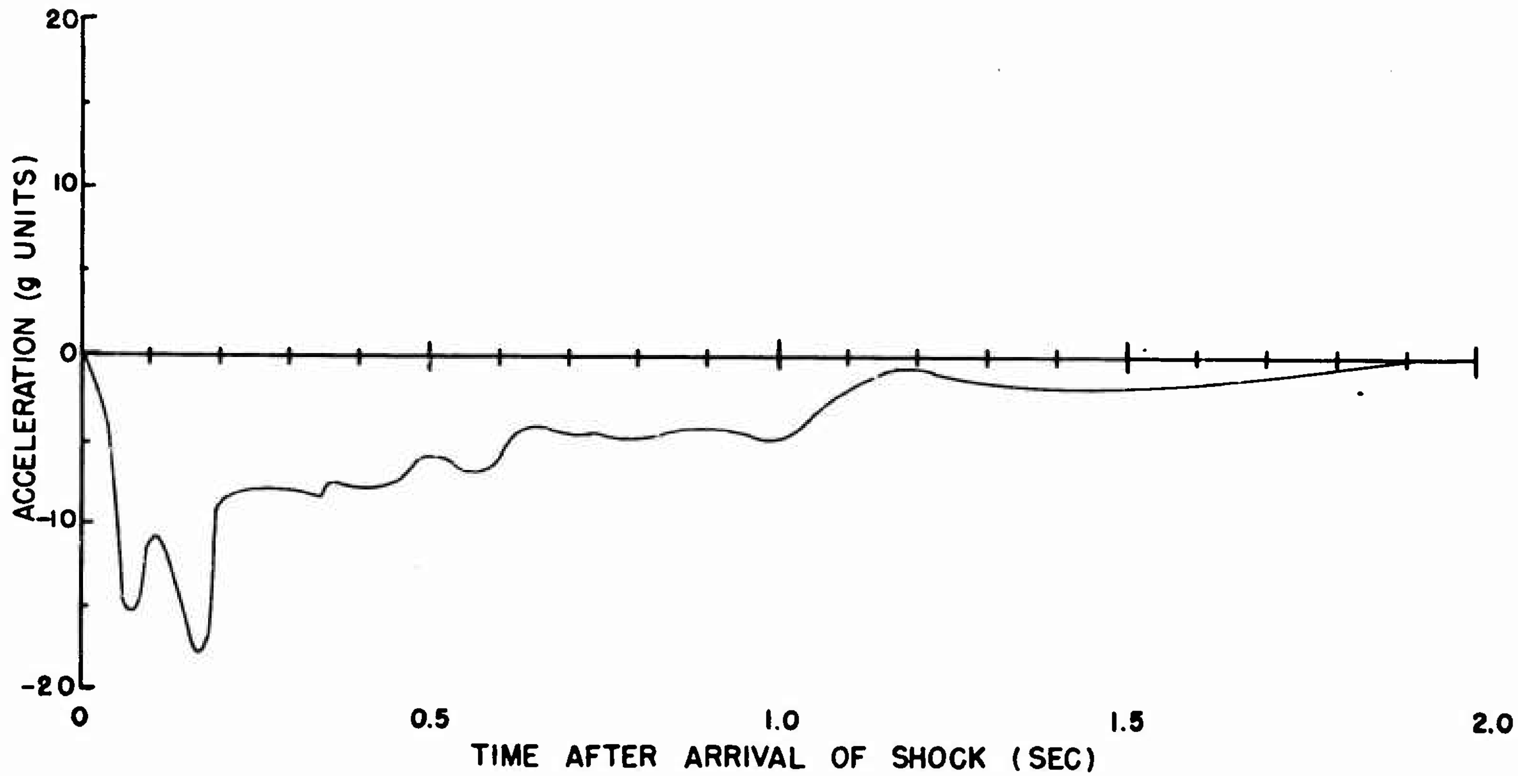

Fig. B.20 Vertical Acceleration for Head-on Tank at 500 Yd from Ground Zero (Accelerometer 2V). Acceleration Record Incomplete. Standard deviation is ±2 g.

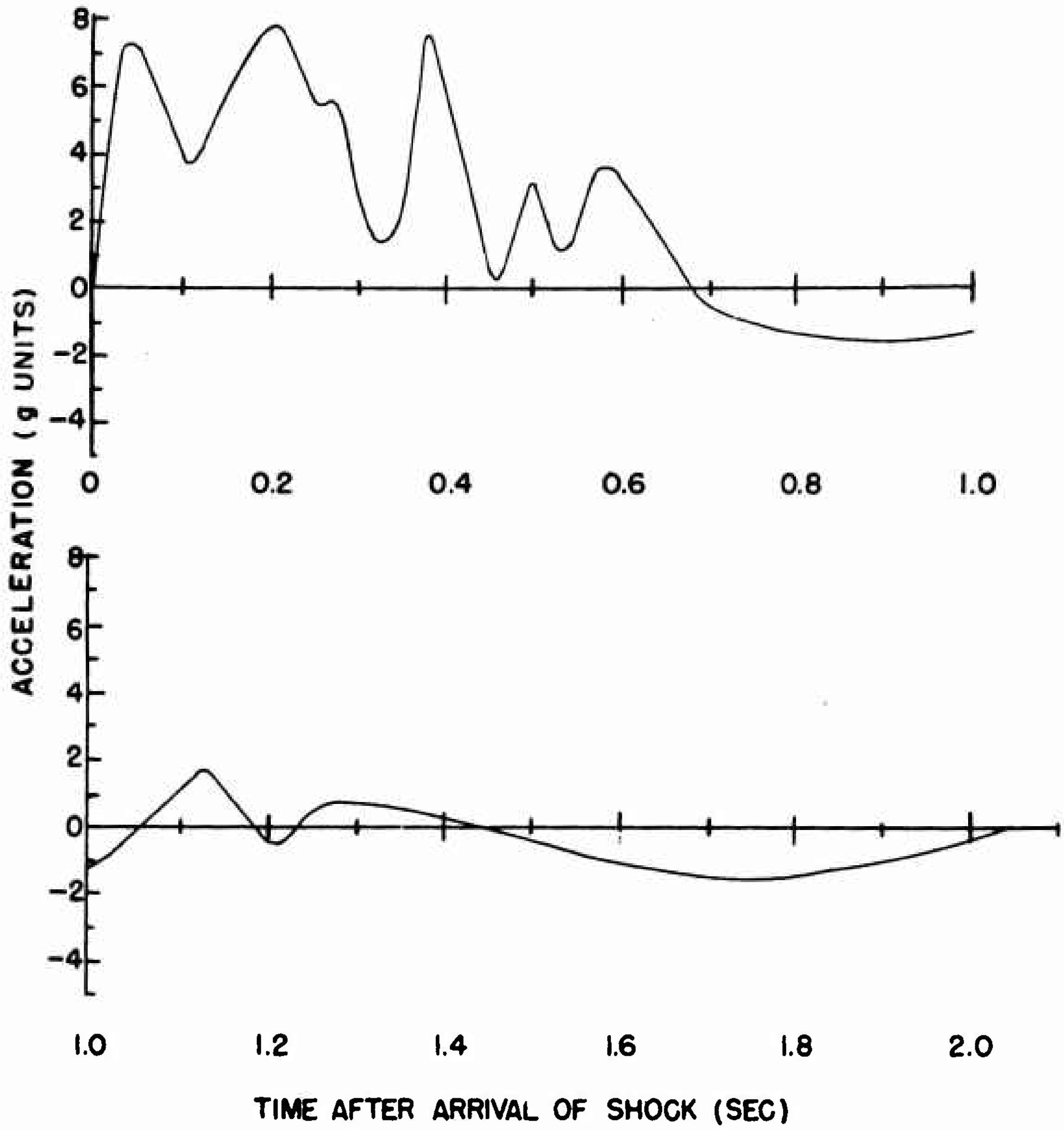

Fig. B.21 Transverse Acceleration for Head-on Tank at 500 Yd from Ground Zero (Accelerometer 2T), Acceleration Record Incomplete. Standard deviation is ±1.4 g.

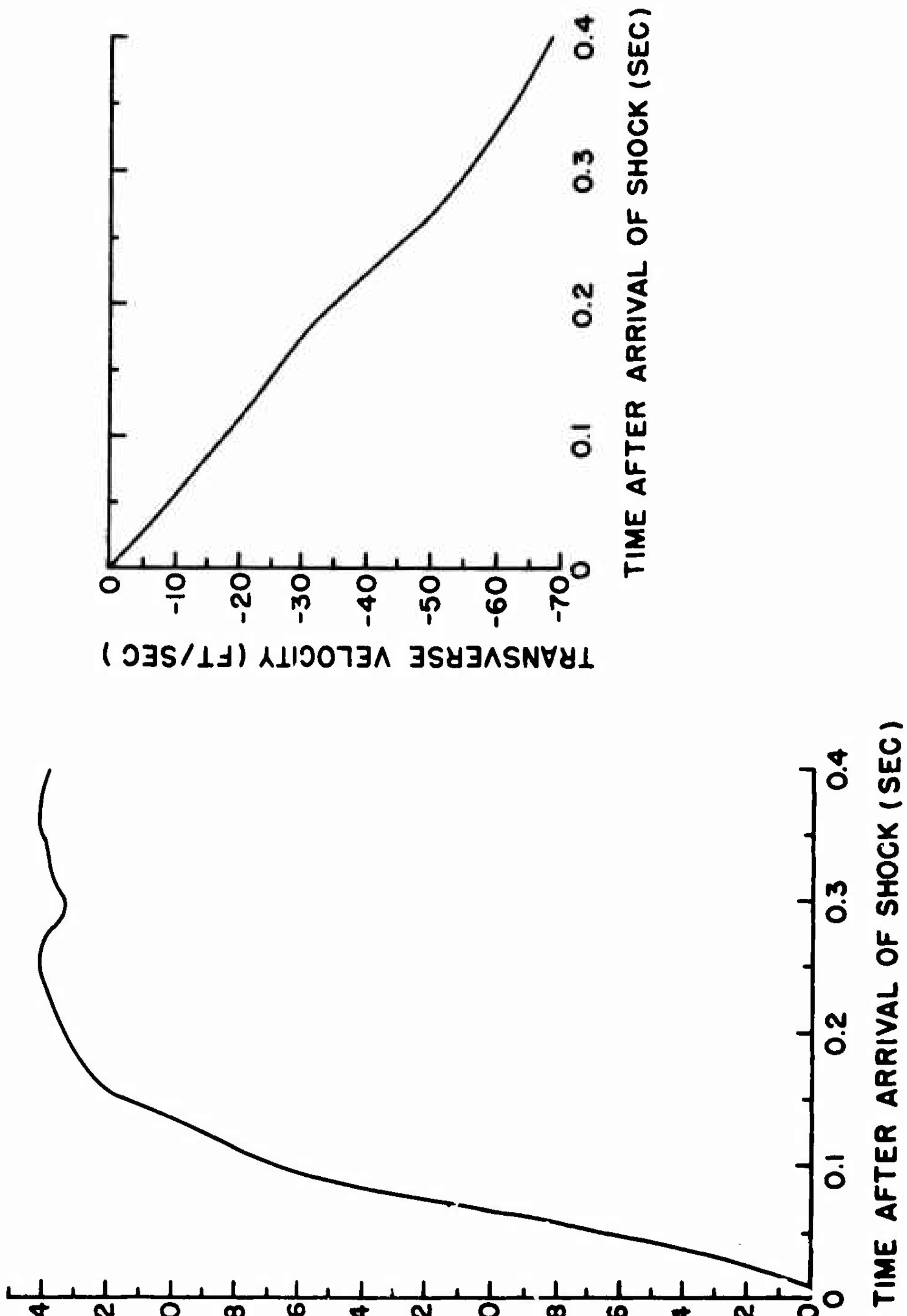

Fig. B.22 Vertical and Transverse Velocities for Head-on Tank at 500 Yd from Ground Zero (Accelerometers 1V and 2T)

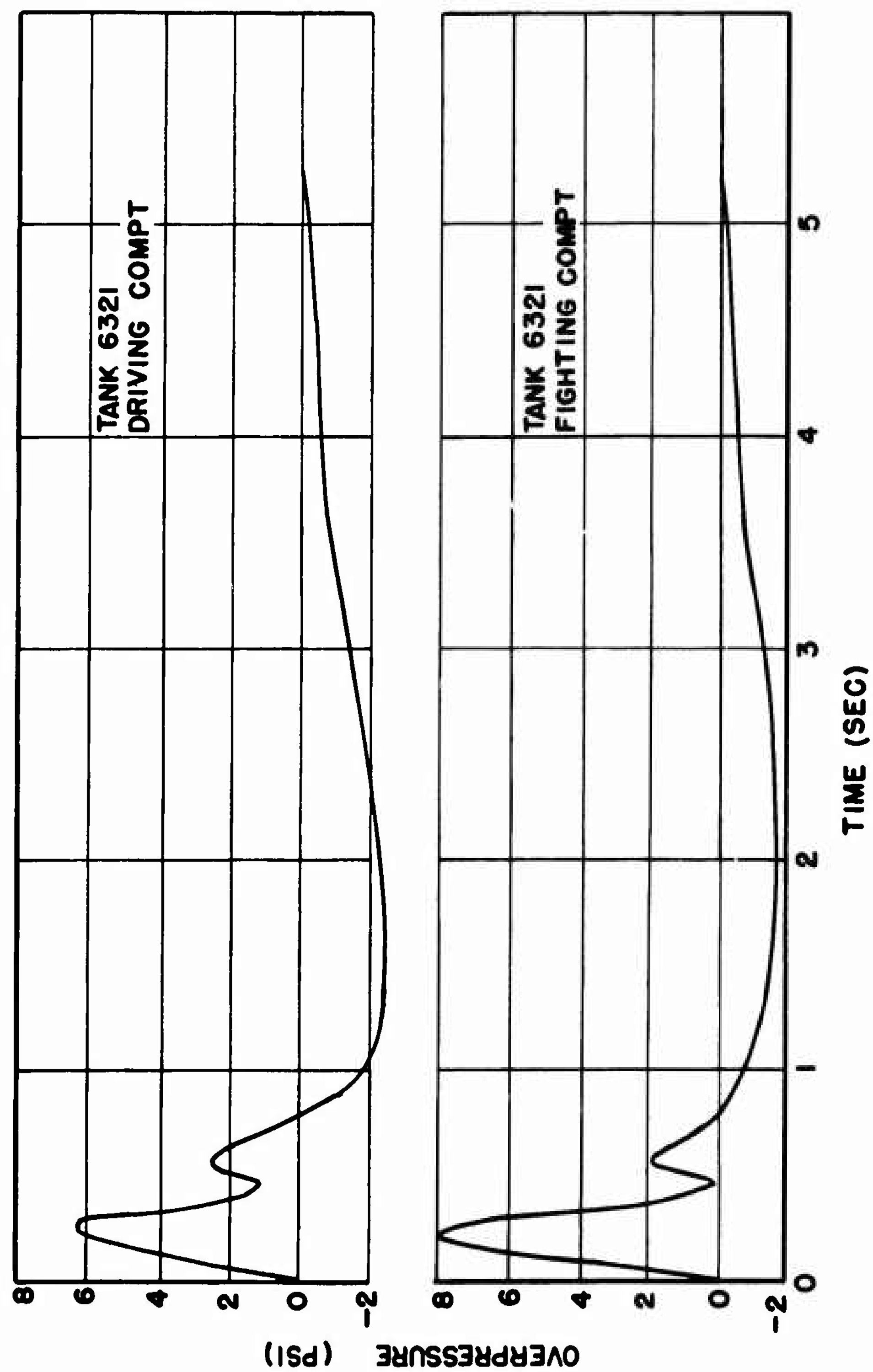

Fig. B.23 Interior Overpressure as a Function of Time for Side-on Tank at 750 Yd from Ground Zero (Magnetic Recorder)

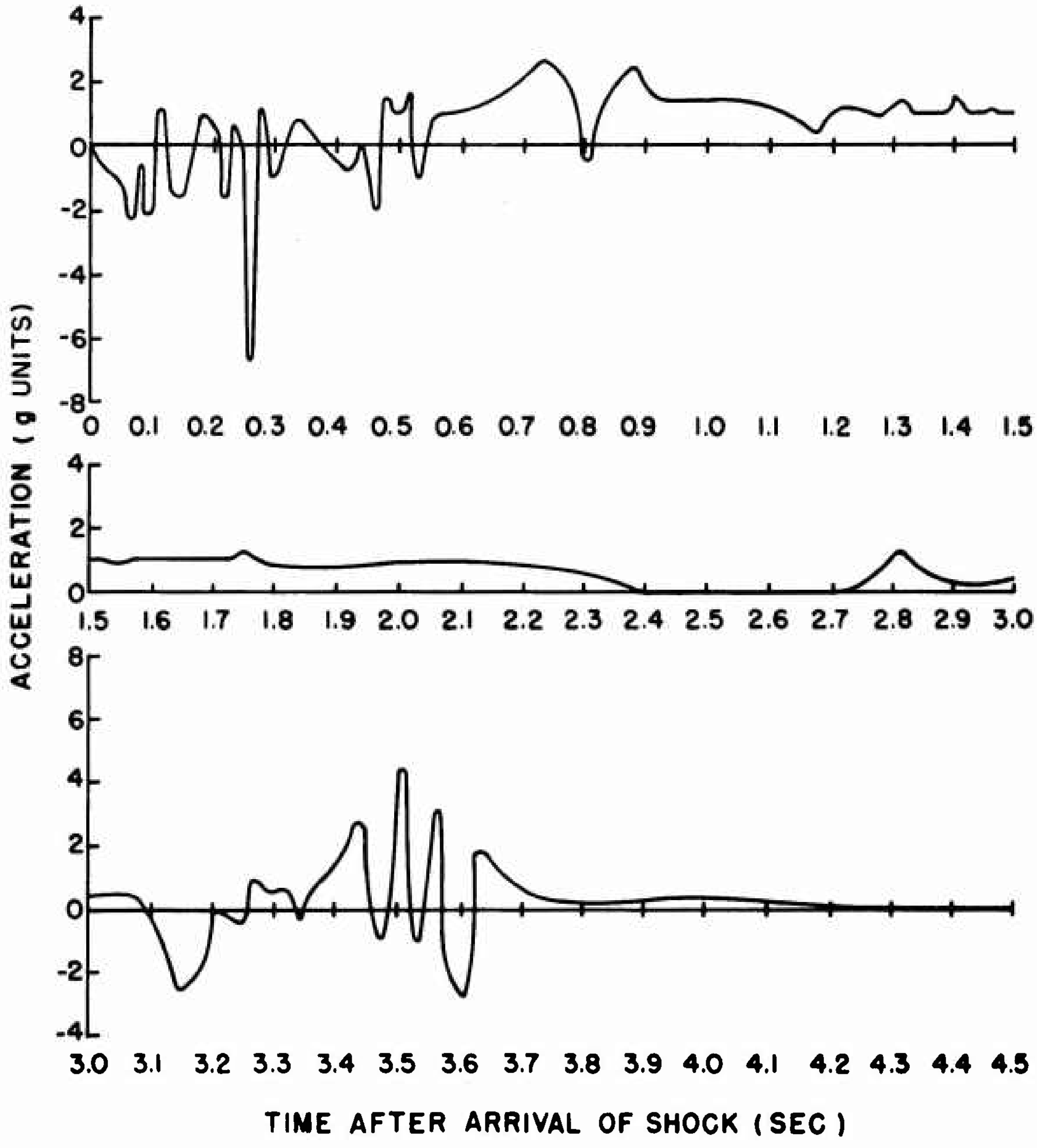

Fig. B.24 Transverse Acceleration for Side-on Tank at 750 Yd from Ground Zero (Accelerometer 1)

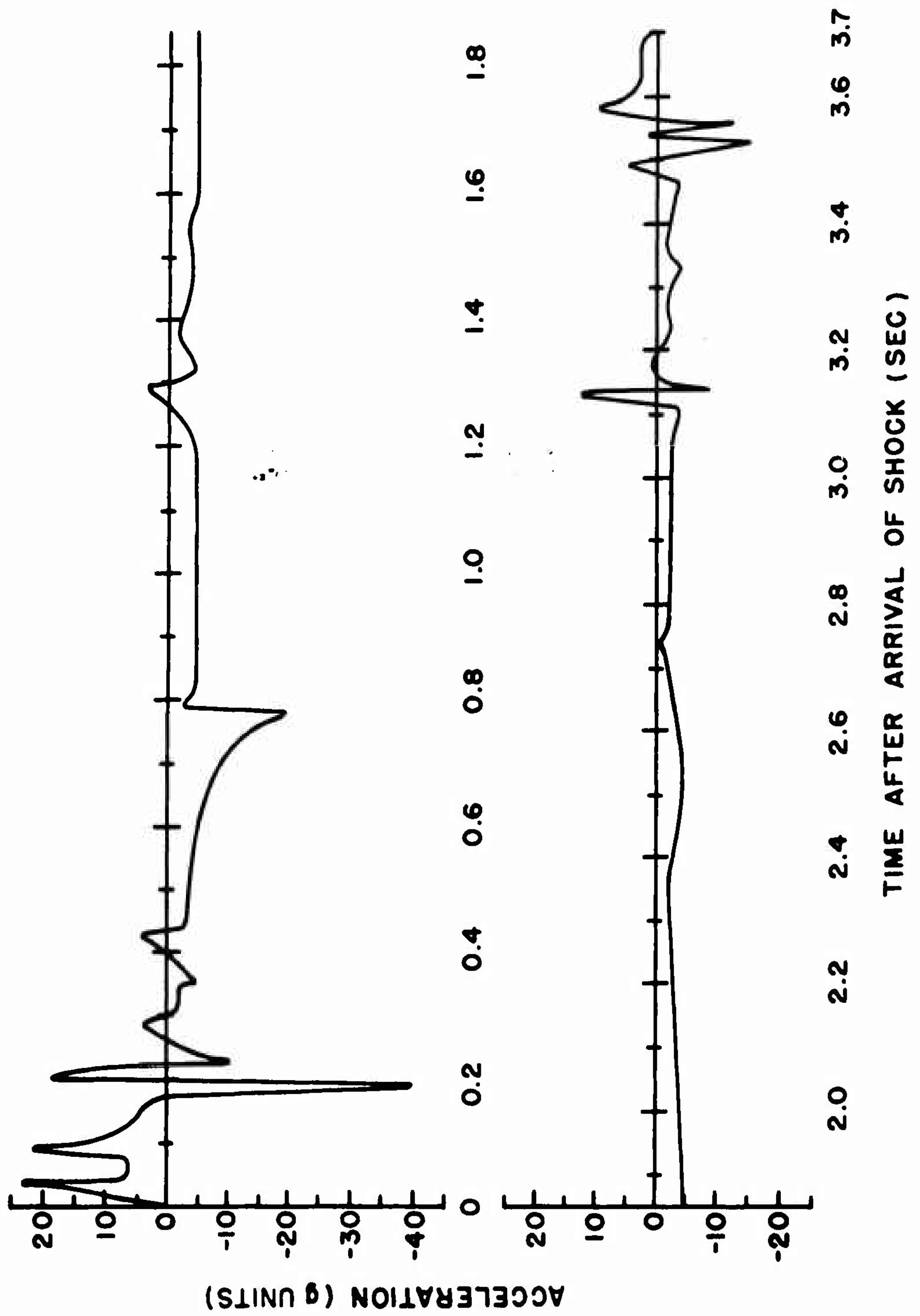

Fig. B.25 Radial Acceleration for Side-on Tank at 750 Yd from Ground Zero (Accelerometer 3)

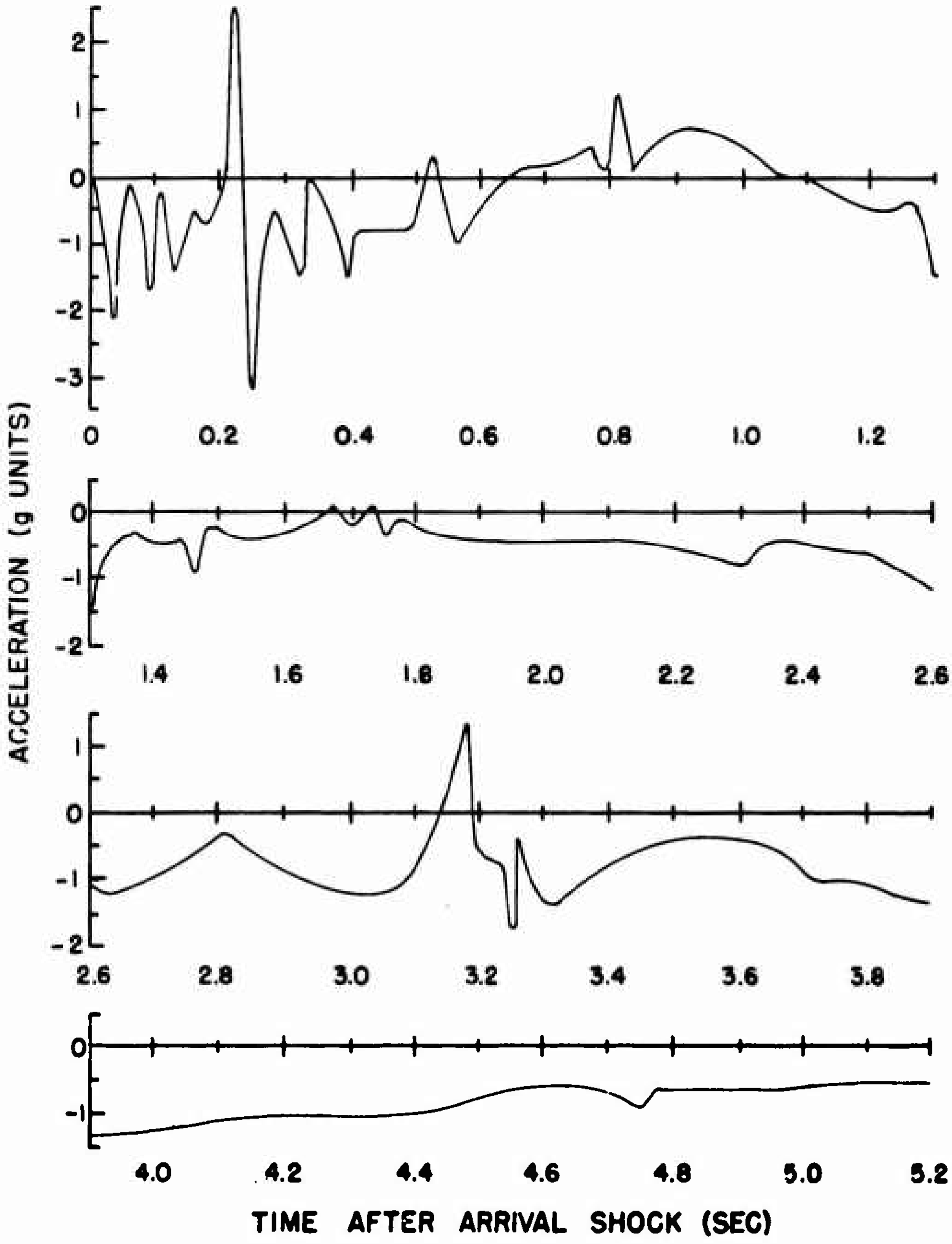

Fig. B.26 Transverse Acceleration for Side-on Tank at 750 Yd from Ground Zero (Accelerometer 4)

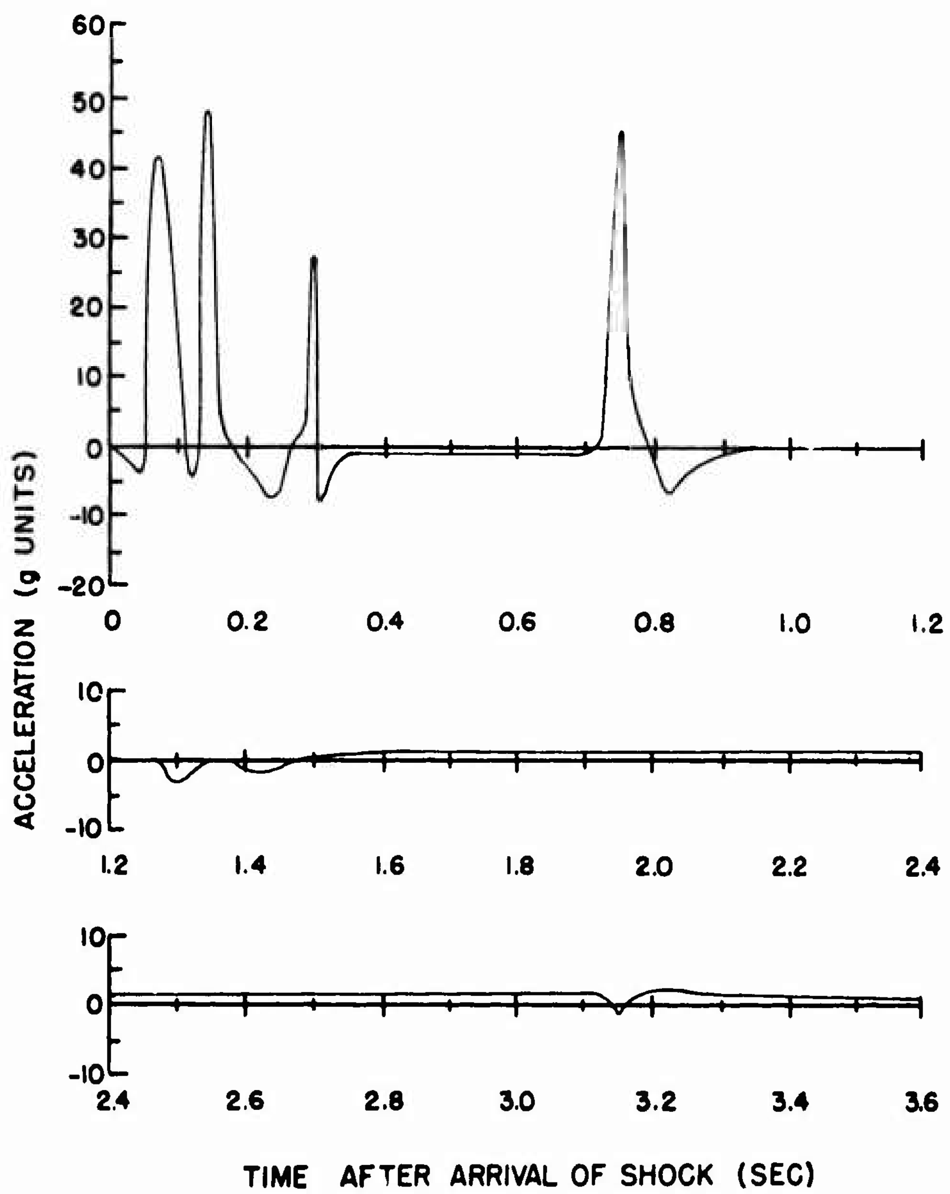

Fig. B.27 Vertical Acceleration for Side-on Tank at 750 Yd from Ground Zero (Accelerometer 5)

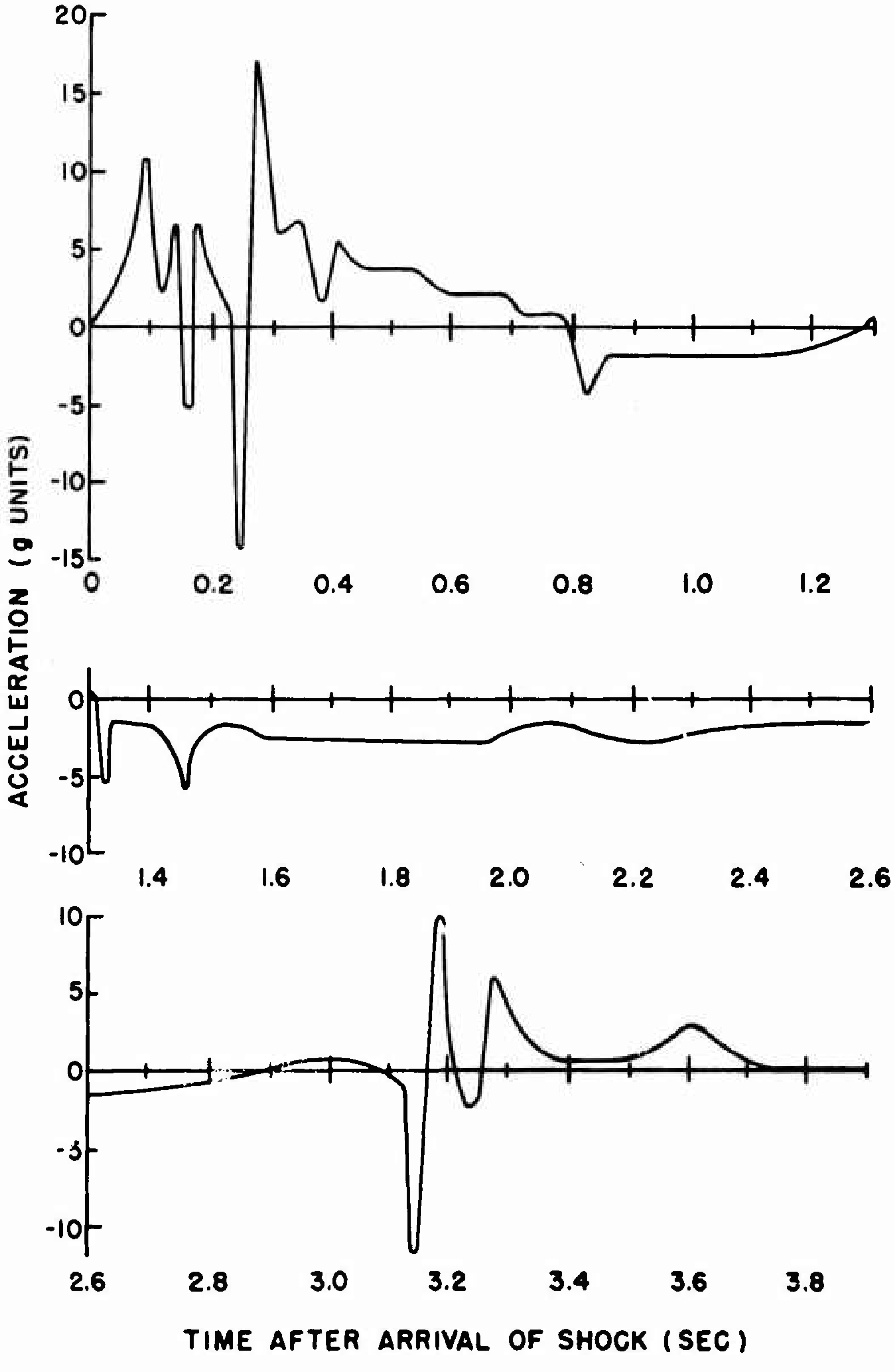

Fig. B.28 Radial Acceleration for Side-on Tank at 750 Yd from Ground Zero (Accelerometer 6)

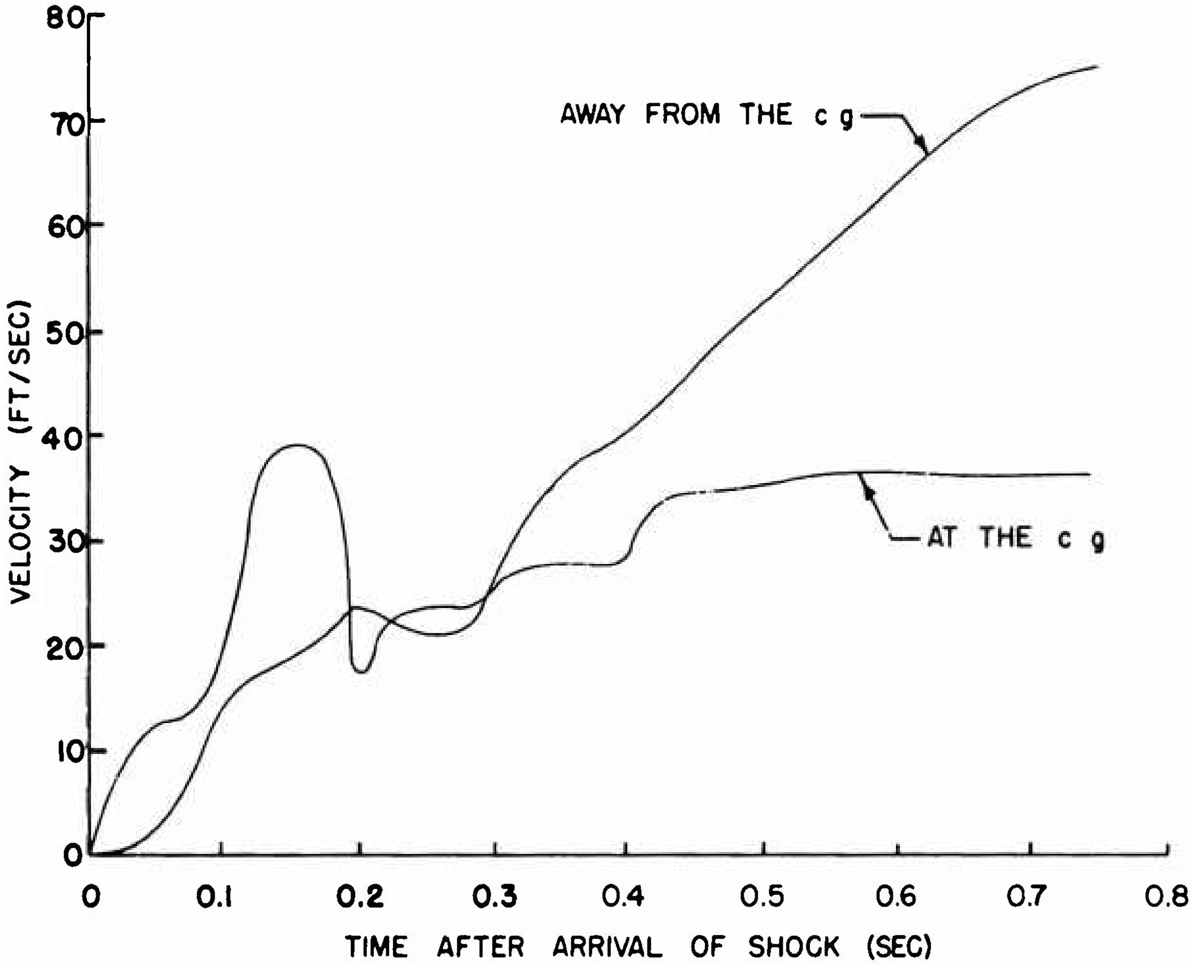

Fig. B.29 Radial Velocities for Side-on Tank at 750 Yd from Ground Zero (Accelerometers 3 and 6)

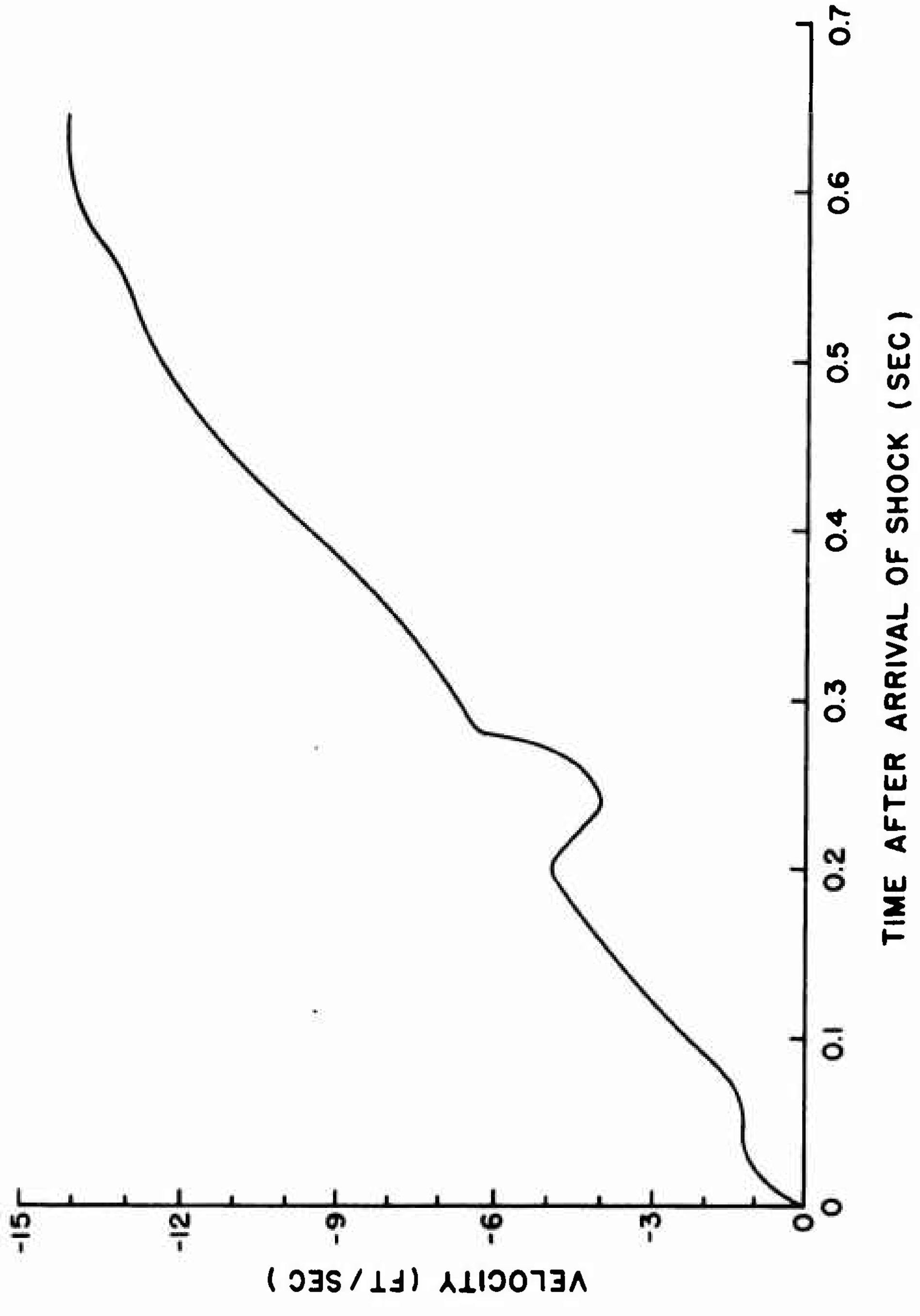

Fig. B.30 Transverse Velocity for Side-on Tank at 750 Yd from Ground Zero (Accelerometer 4)

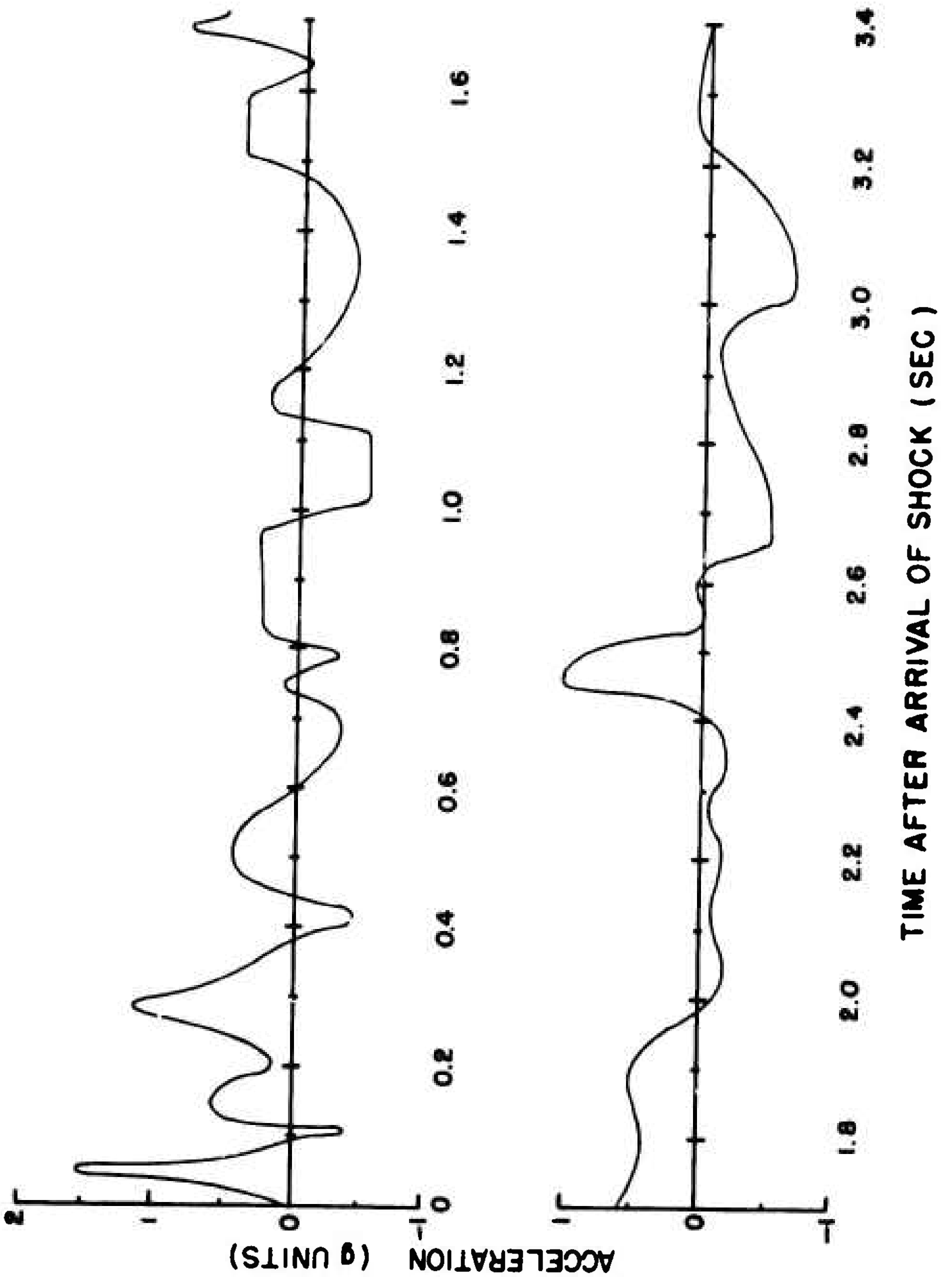

Fig. B.31 Radial Acceleration for Head-on Tank at 750 Yd from Ground Zero (Accelerometer 1L). Standard deviation is ±0.3 g.

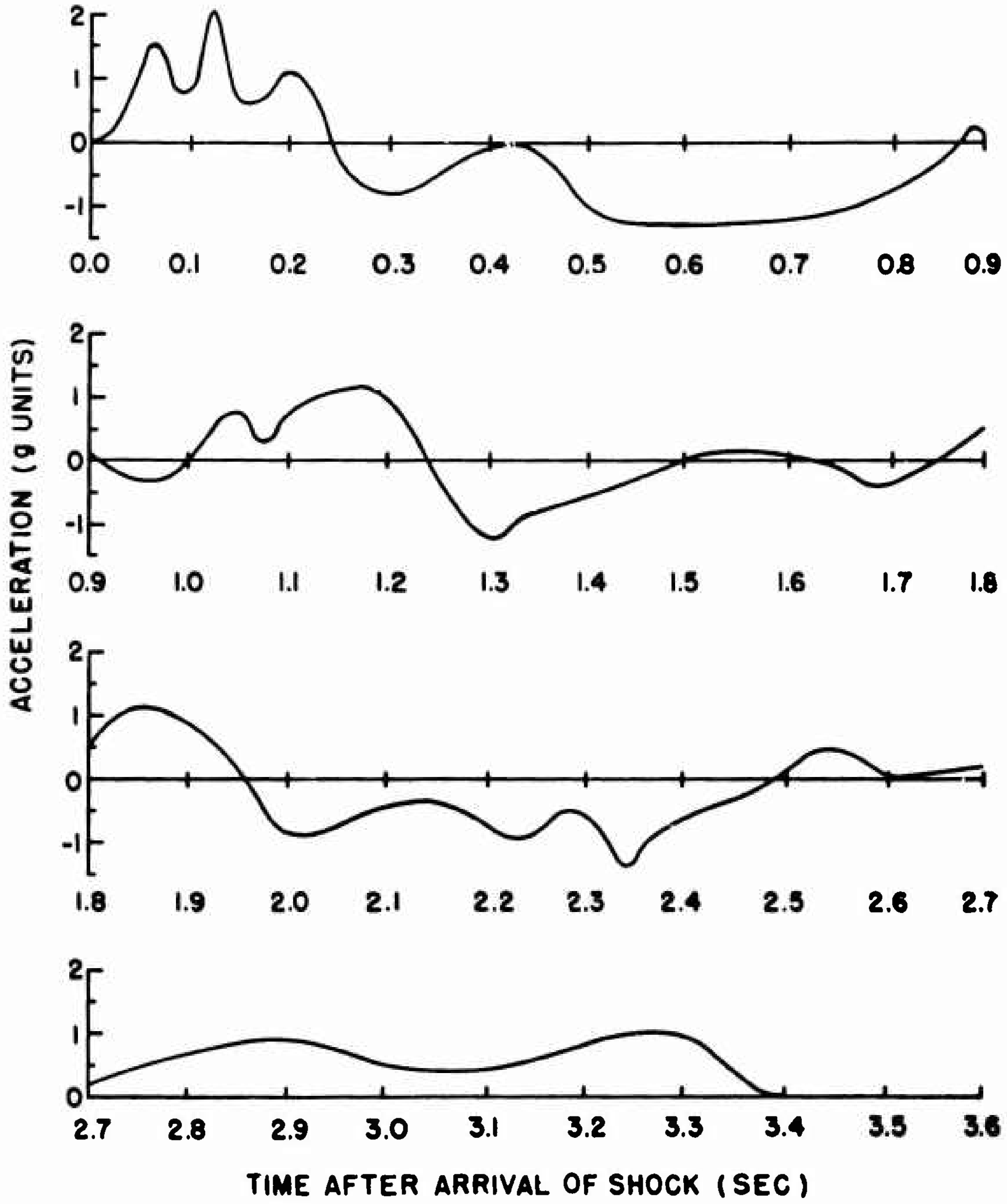

Fig. B.32 Vertical Acceleration for Head-on Tank at 750 Yd from Ground Zero (Accelerometer 1V). Standard deviation is ±0.5 g.

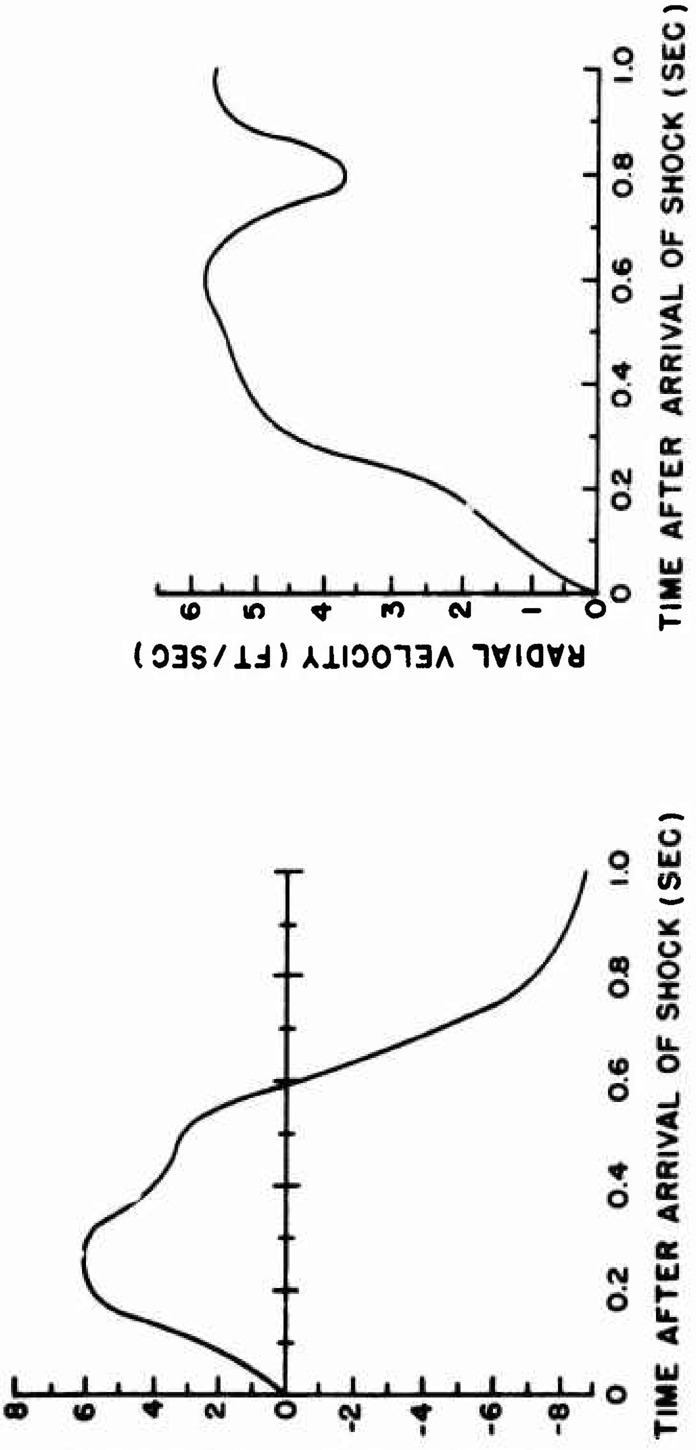

Fig. B.33 Vertical and Radial Velocities for Head-on Tank at 750 Yd from Ground Zero (Accelerometers 1V and 1L)

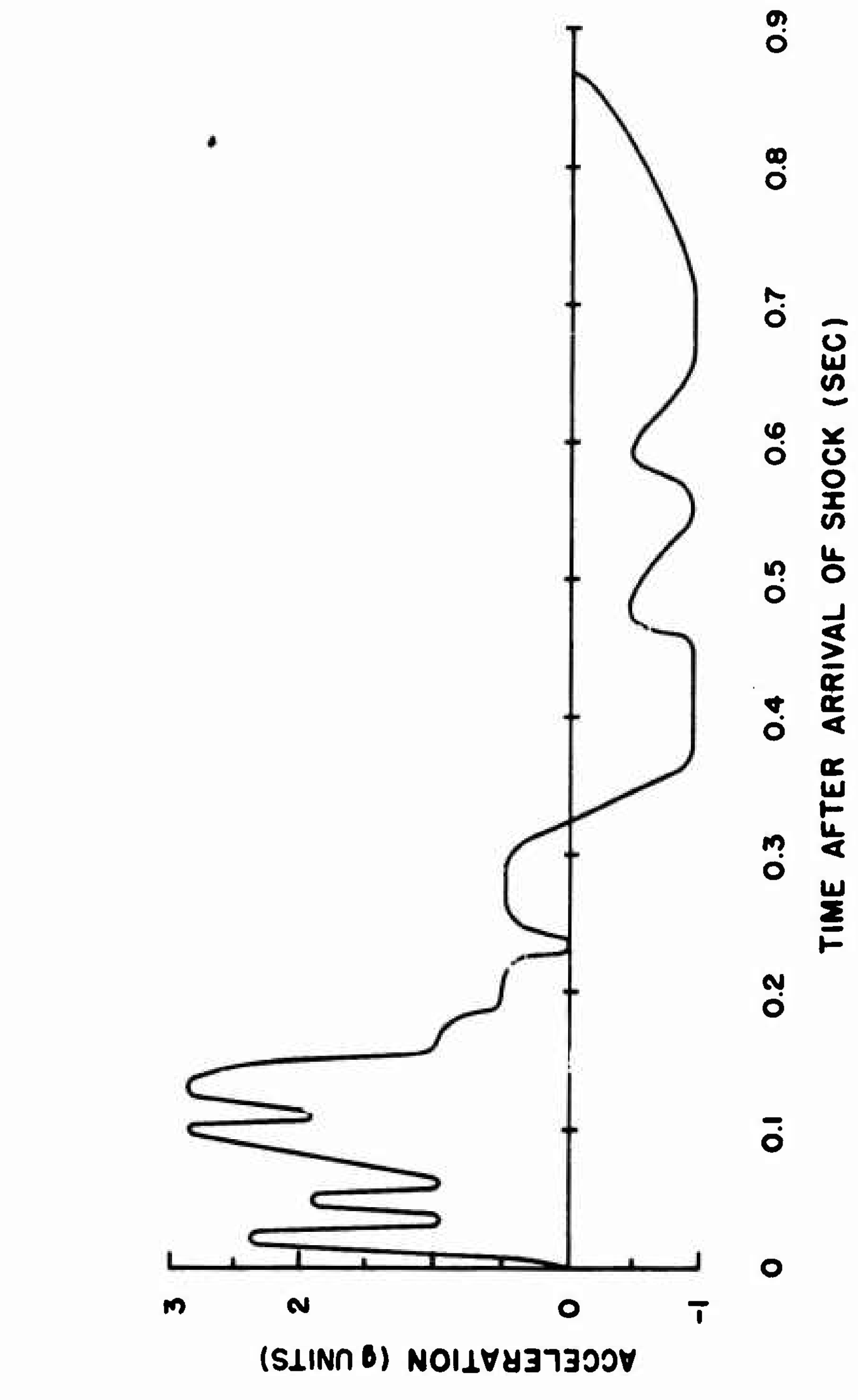

Fig. B.34 Radial Acceleration for Side-on Tank at 1000 Yd from Ground Zero (Accelerometer 1T). Standard deviation is ±0.5 g.

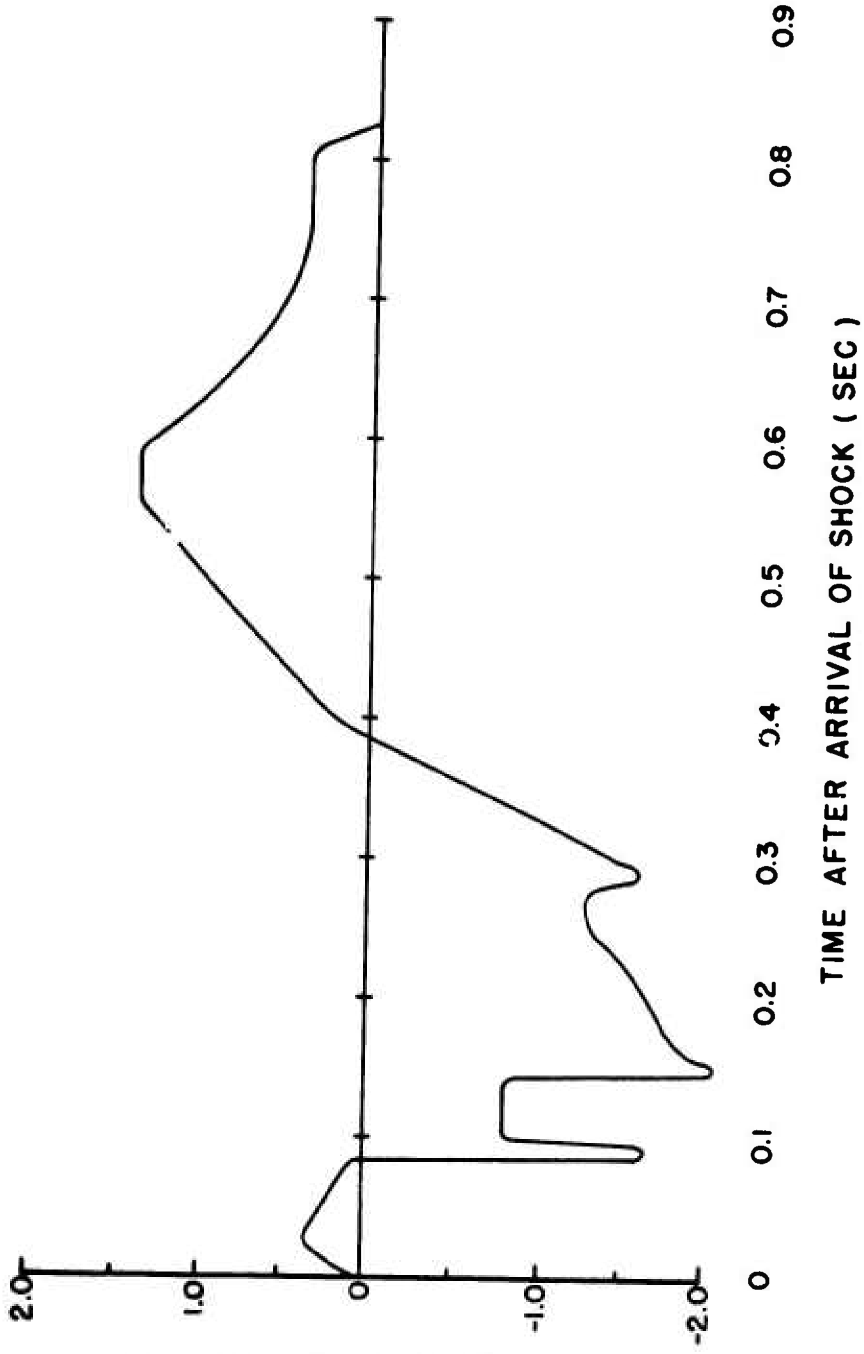

Fig. B.35 Vertical Acceleration for Side-on Tank at 1000 Yd from Ground Zero (Accelerometer 1V). Standard deviation is ±0.2 g.

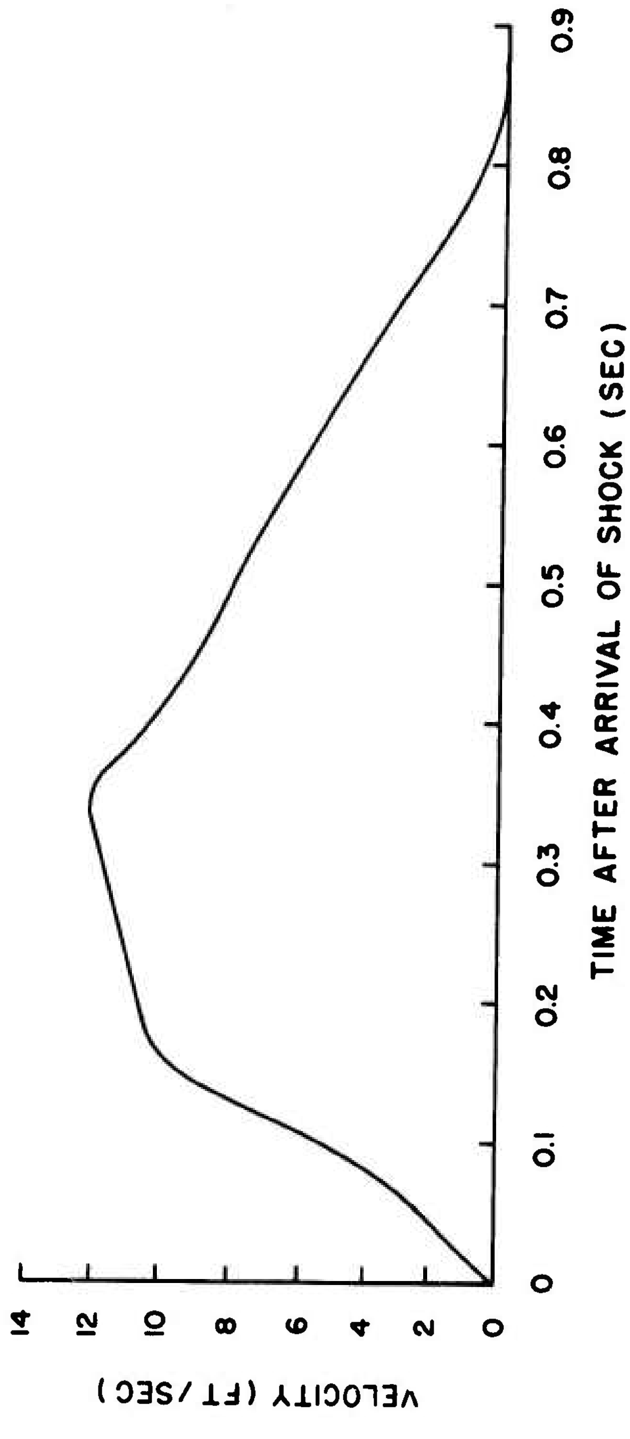

Fig. B.36 Radial Velocity for Side-on Tank at 1000 Yd from Ground Zero (Accelerometer 1T)

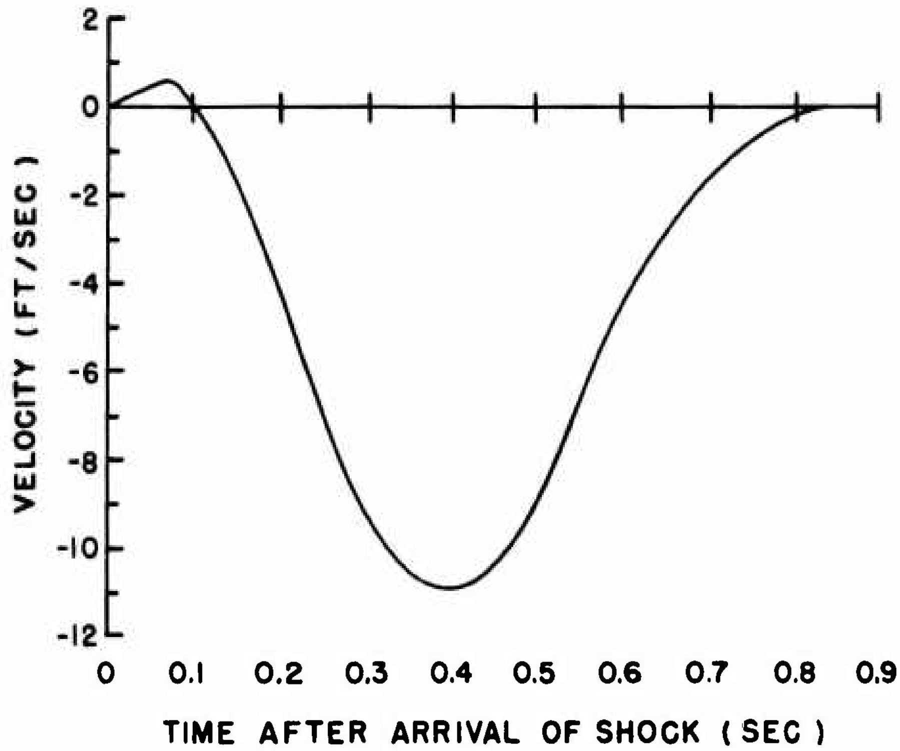

Fig. B.37 Vertical Velocity for Side-on Tank at 1000 Yd from Ground Zero (Accelerometer 1V)

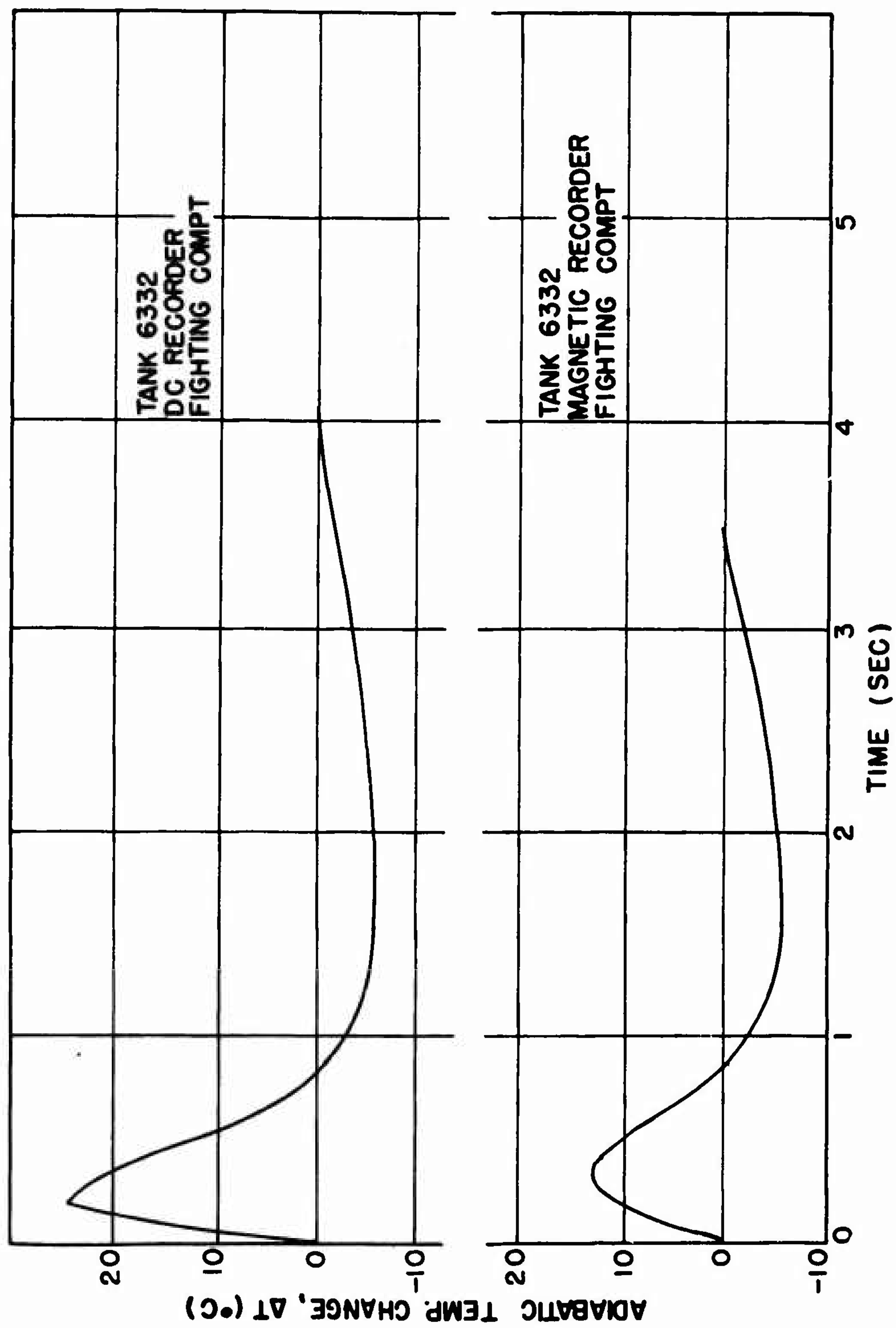

Fig. B.38 Adiabatic Temperature vs Time inside Head-on Tank at 1000 Yd from Ground Zero (Magnetic Recorder and D-c Recorder)

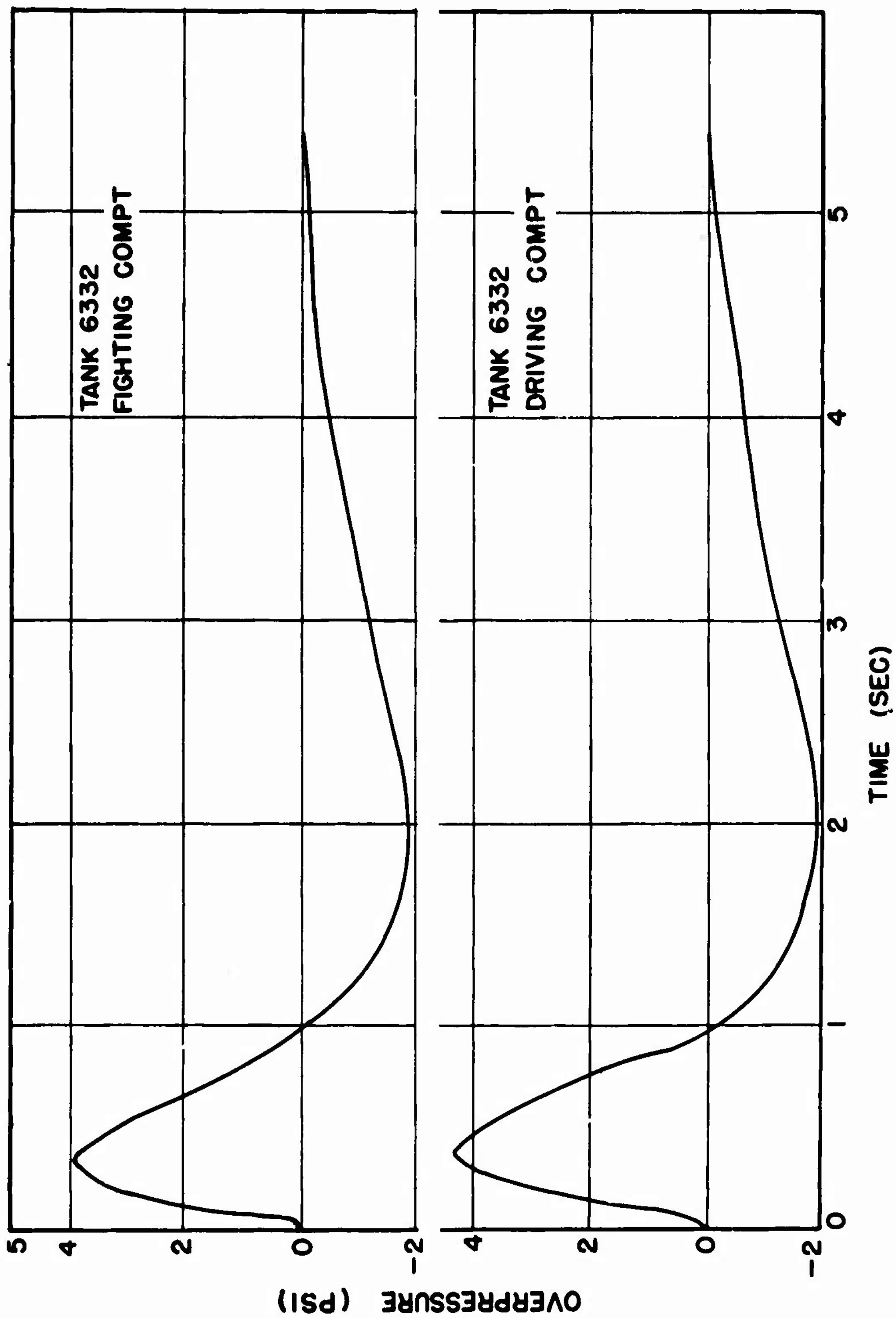

Fig. B.39 Interior Overpressure as a Function of Time for Head-on Tank at 1000 Yd from Ground Zero (Magnetic Recorder)

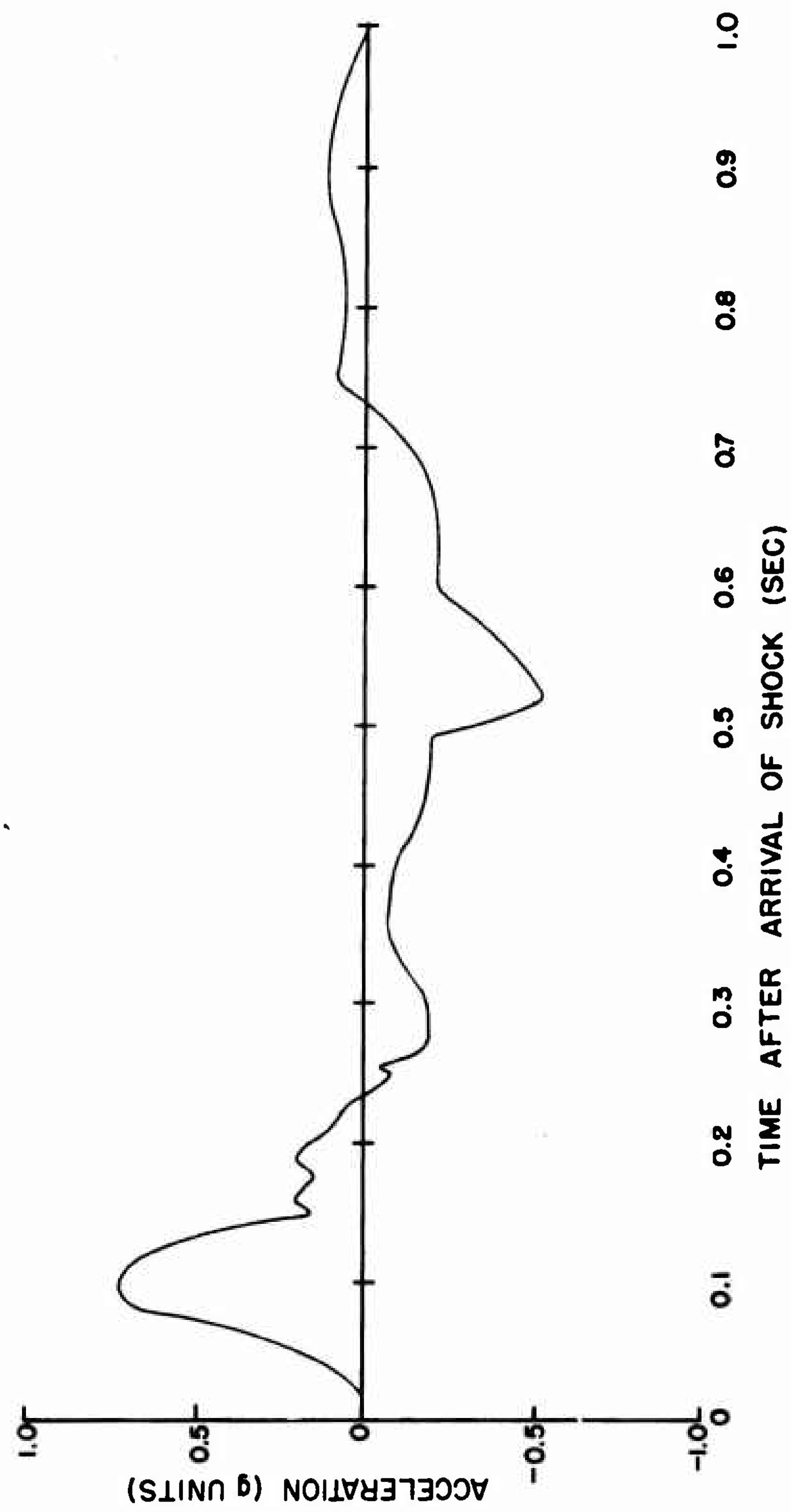

Fig. B.40 Radial Acceleration for Head-on Tank at 1000 Yd from Ground Zero (Accelerometer 1)

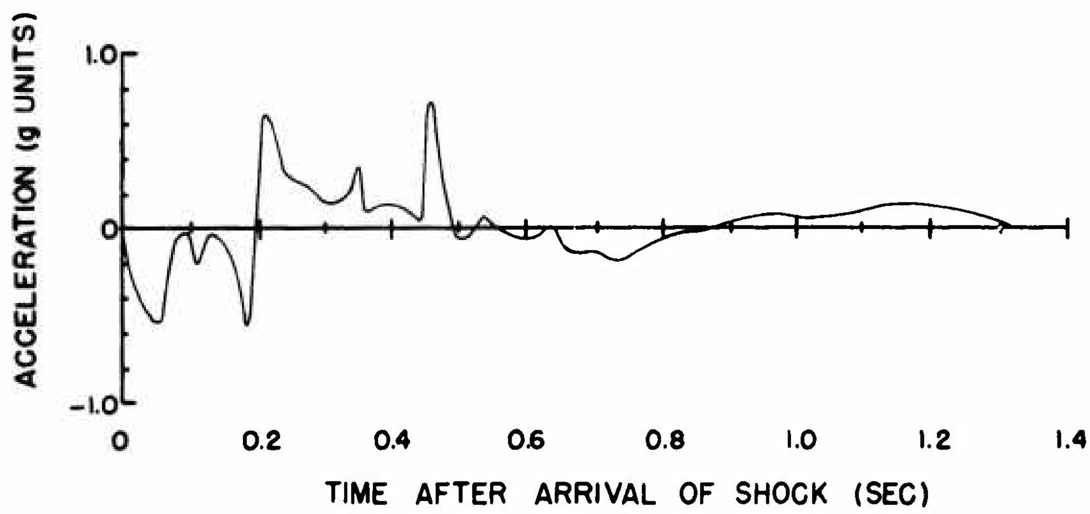

Fig. B.41 Vertical Acceleration for Head-on Tank at 1000 Yd from Ground Zero (Accelerometer 2)

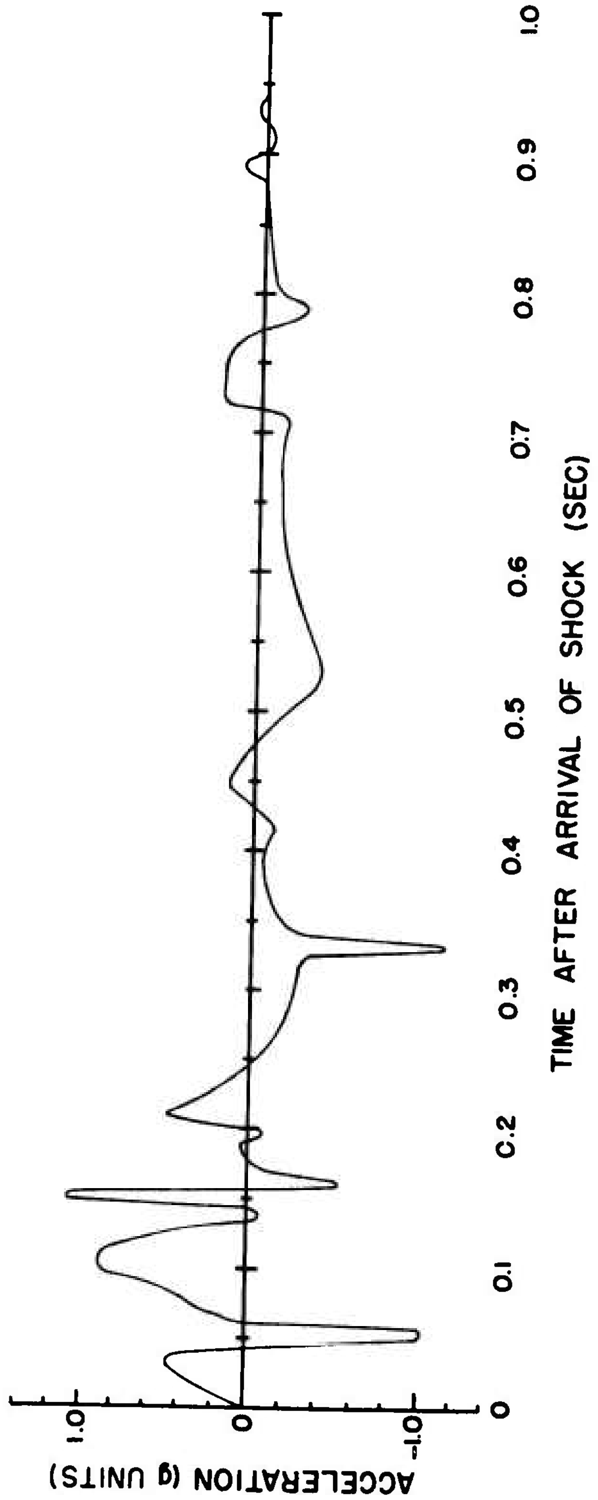

Fig. B.42 Transverse Acceleration for Head-on Tank at 1000 Yd from Ground Zero (Accelerometer 3)

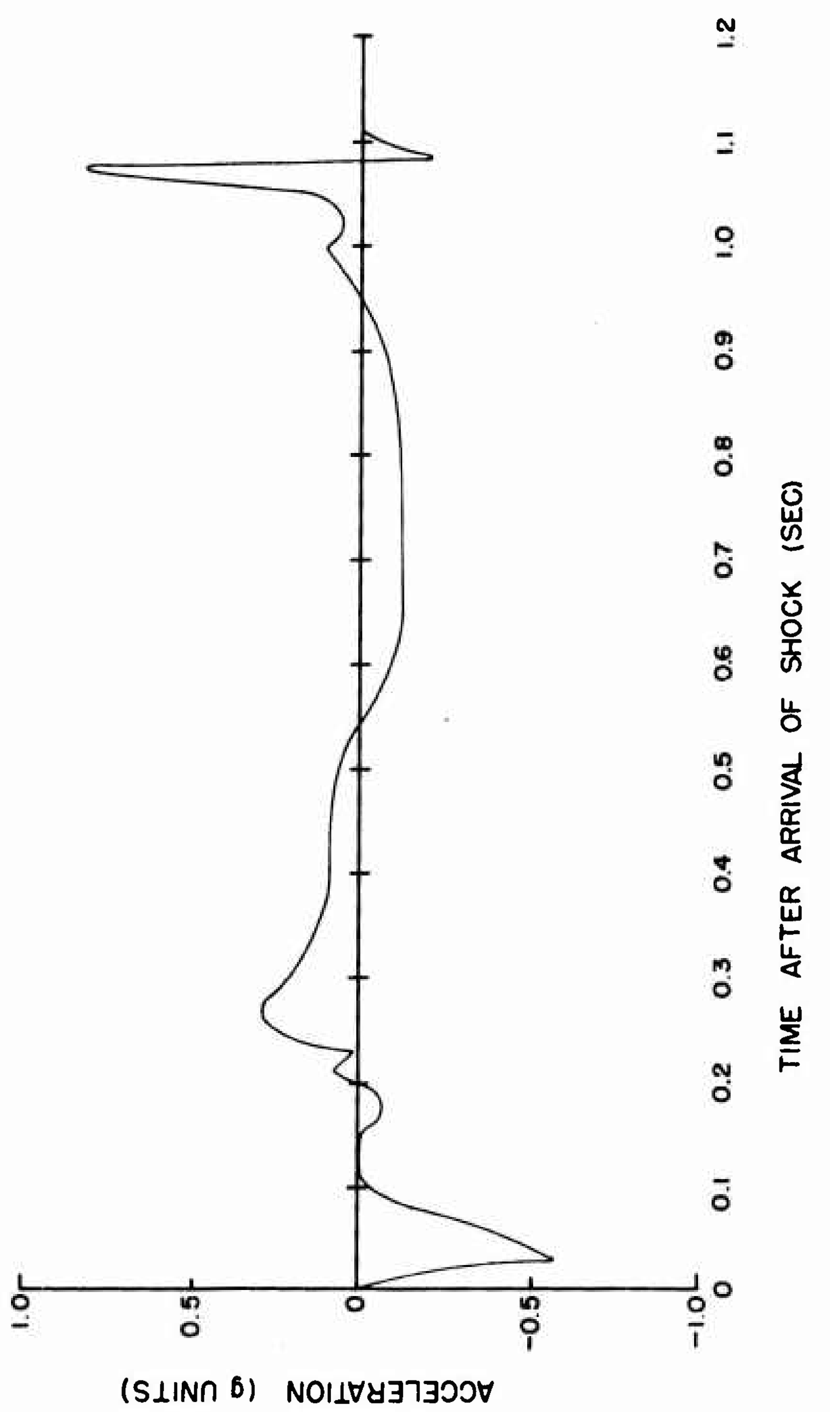

Fig. B.43 Vertical Acceleration for Head-on Tank at 1000 Yd from Ground Zero (Accelerometer 5)

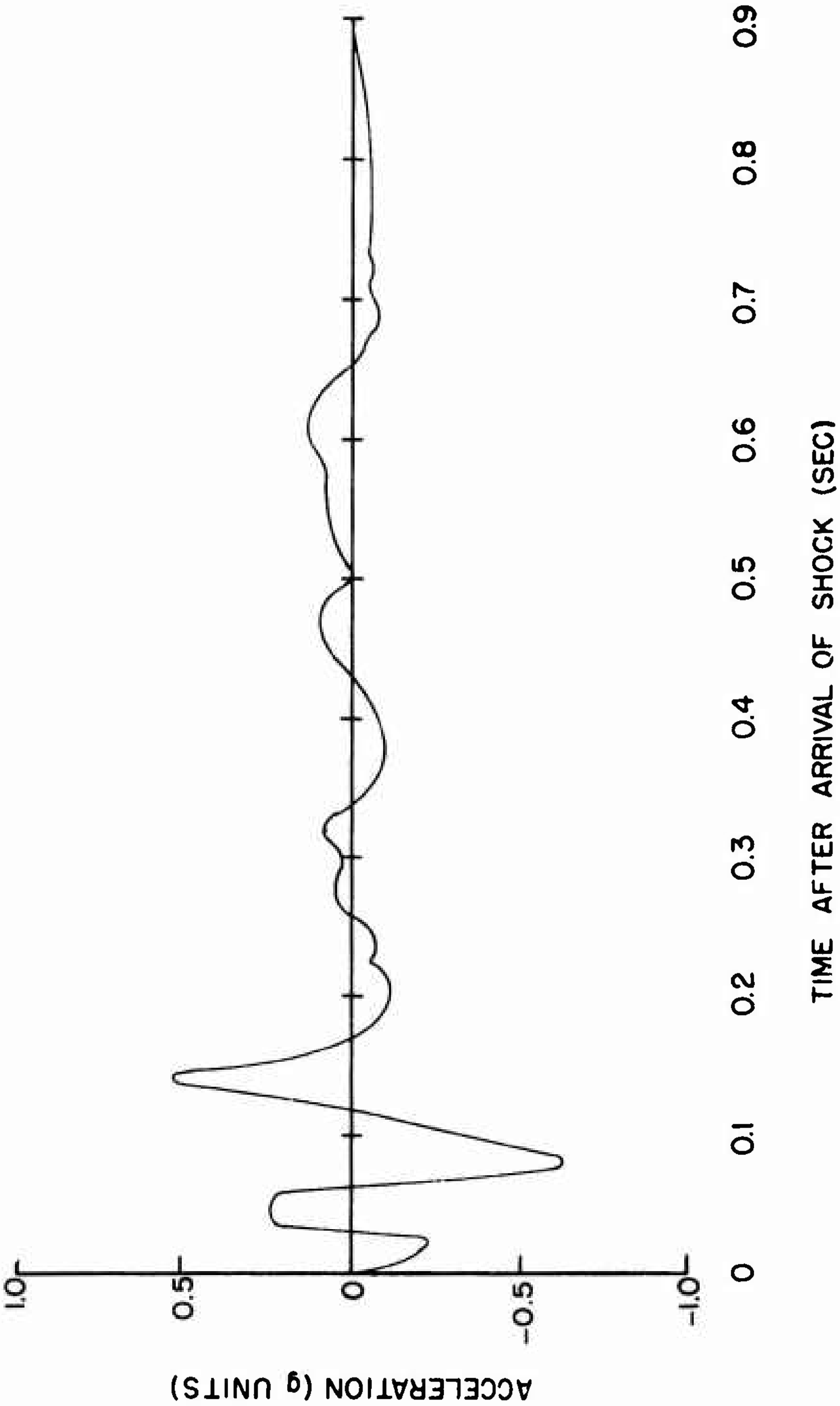

Fig. B.44 Transverse Acceleration for Head-on Tank at 1000 Yd from Ground Zero (Accelerometer 6)

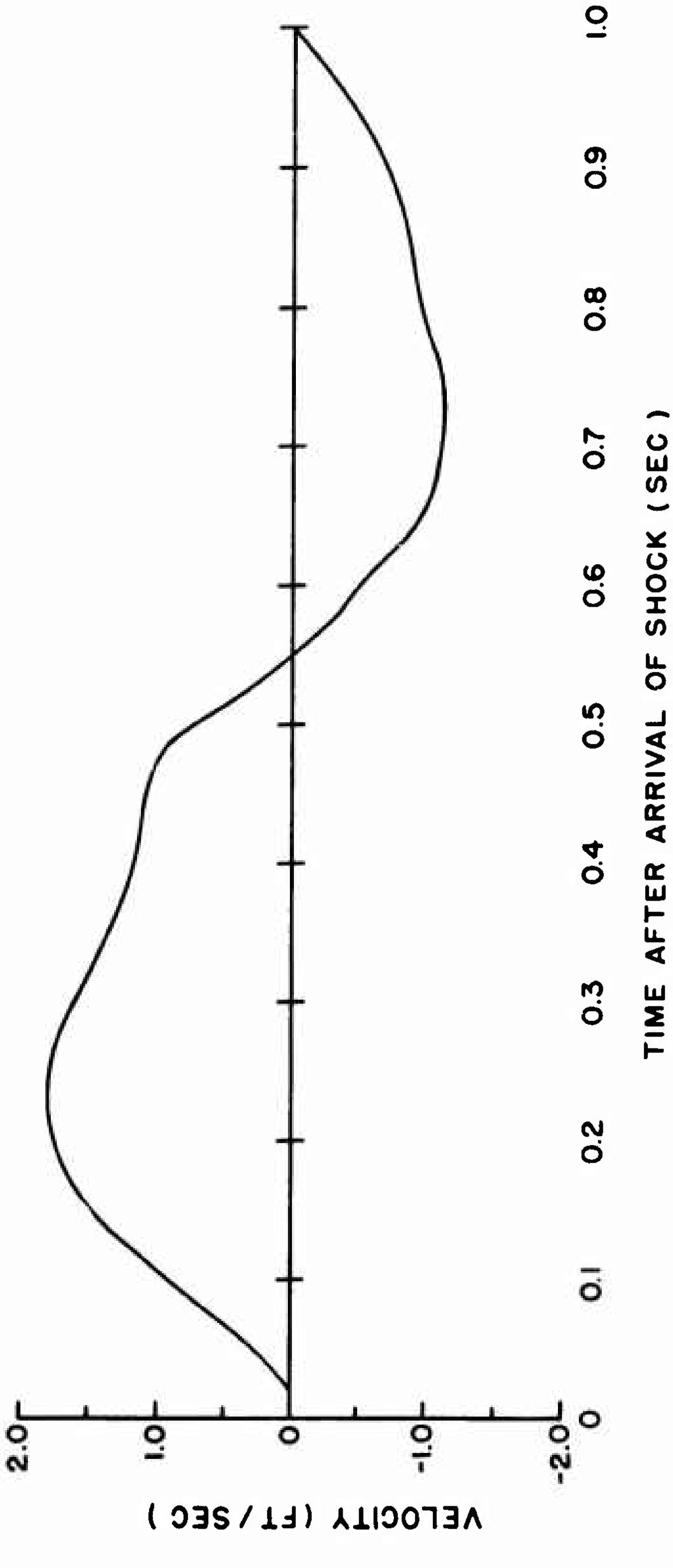

Fig. B.45 Radial Velocity for Head-on Tank at 1000 Yd from Ground Zero (Accelerometer 1)

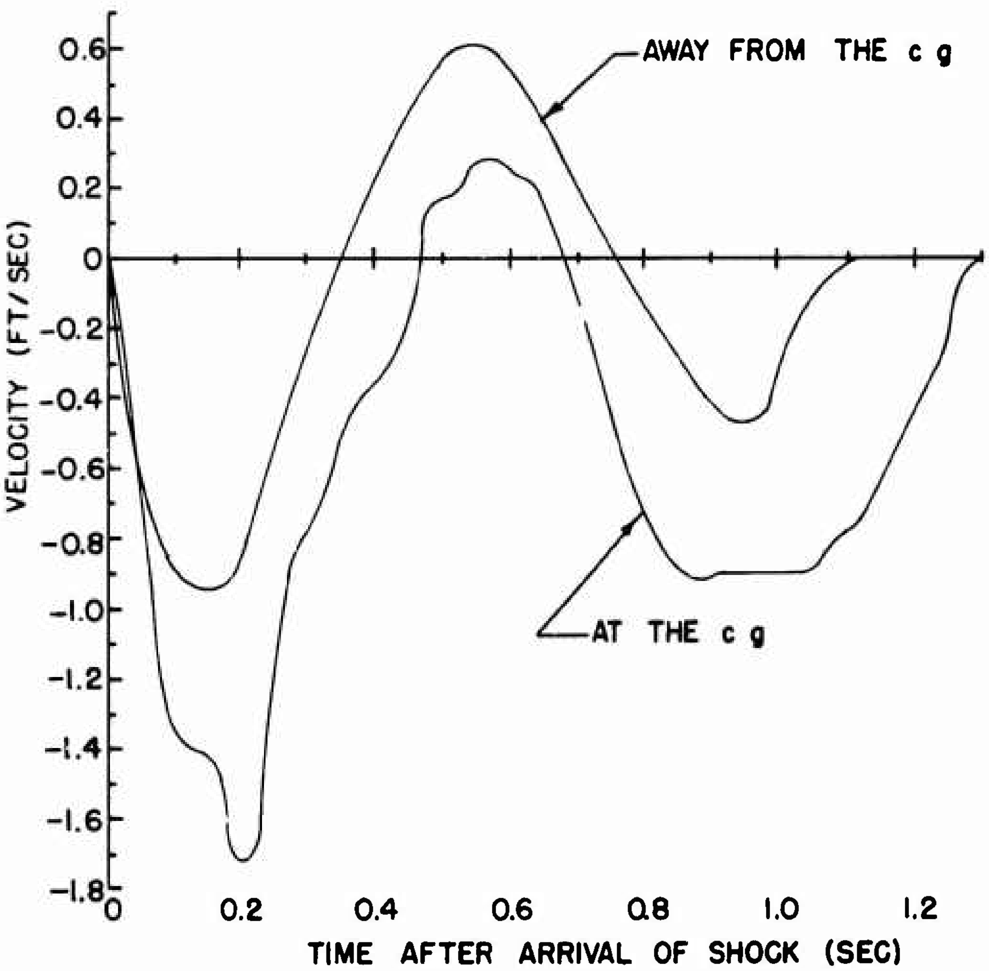

Fig. B.46 Vertical Velocities for Head-on Tank at 1000 Yd from Ground Zero (Accelerometers 2 and 5)

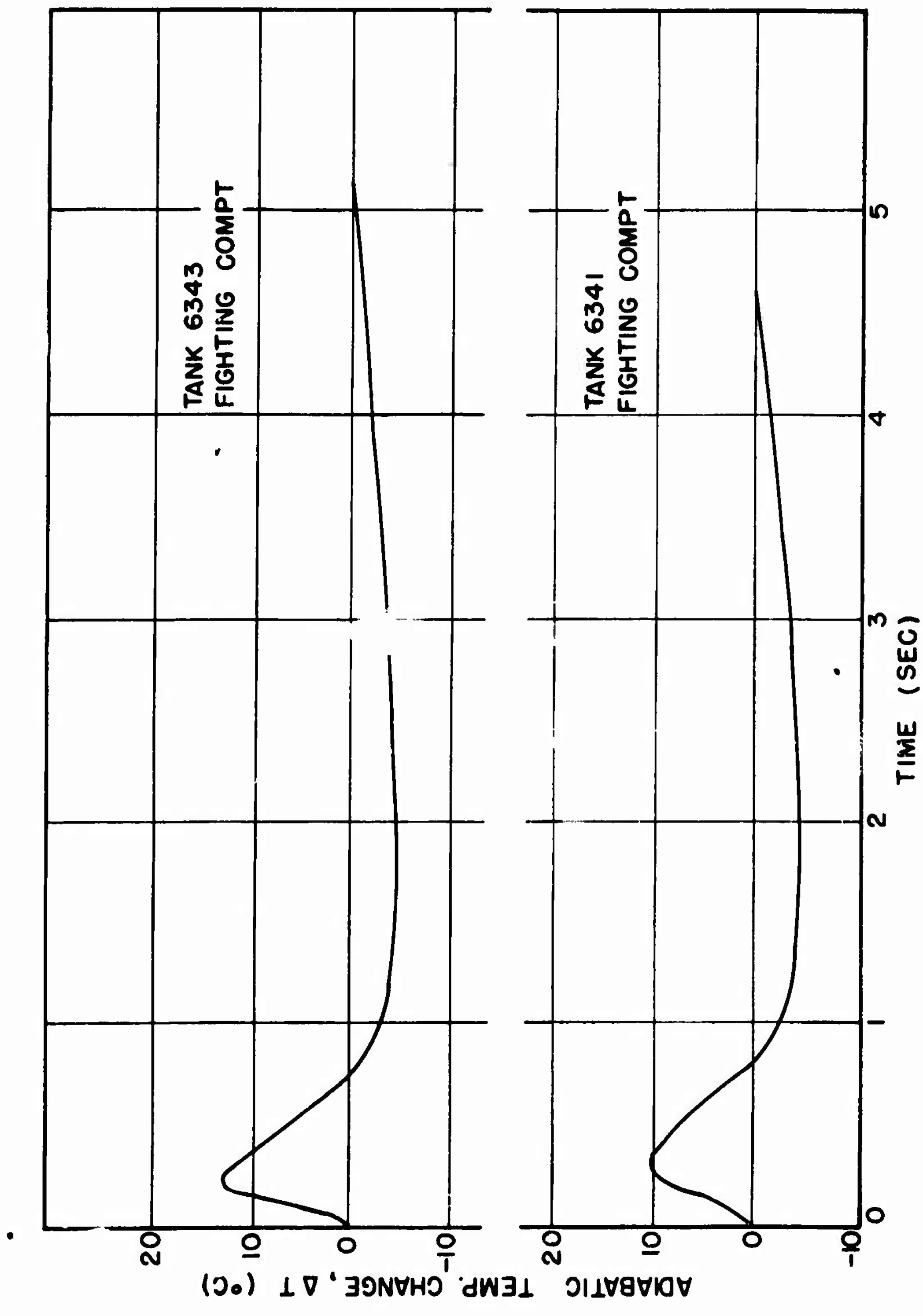

Fig. B.47 Adiabatic Temperature vs Time inside Two Tanks at 1233 Yd from Ground Zero (Magnetic Recorder)

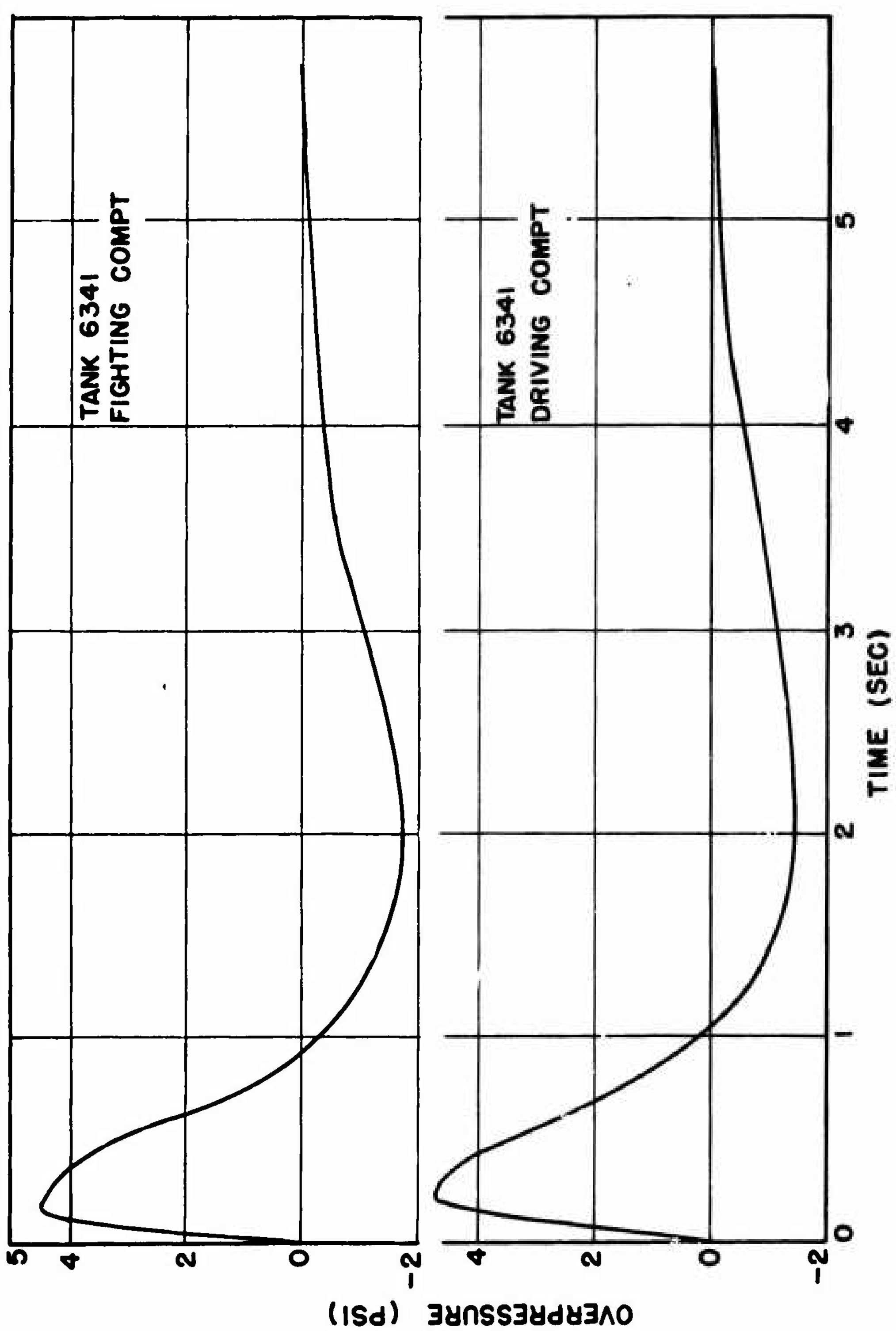

Fig. B.48 Interior Overpressure as a Function of Time for Side-on Tank at 1233 Yd from Ground Zero (Magnetic Recorder)

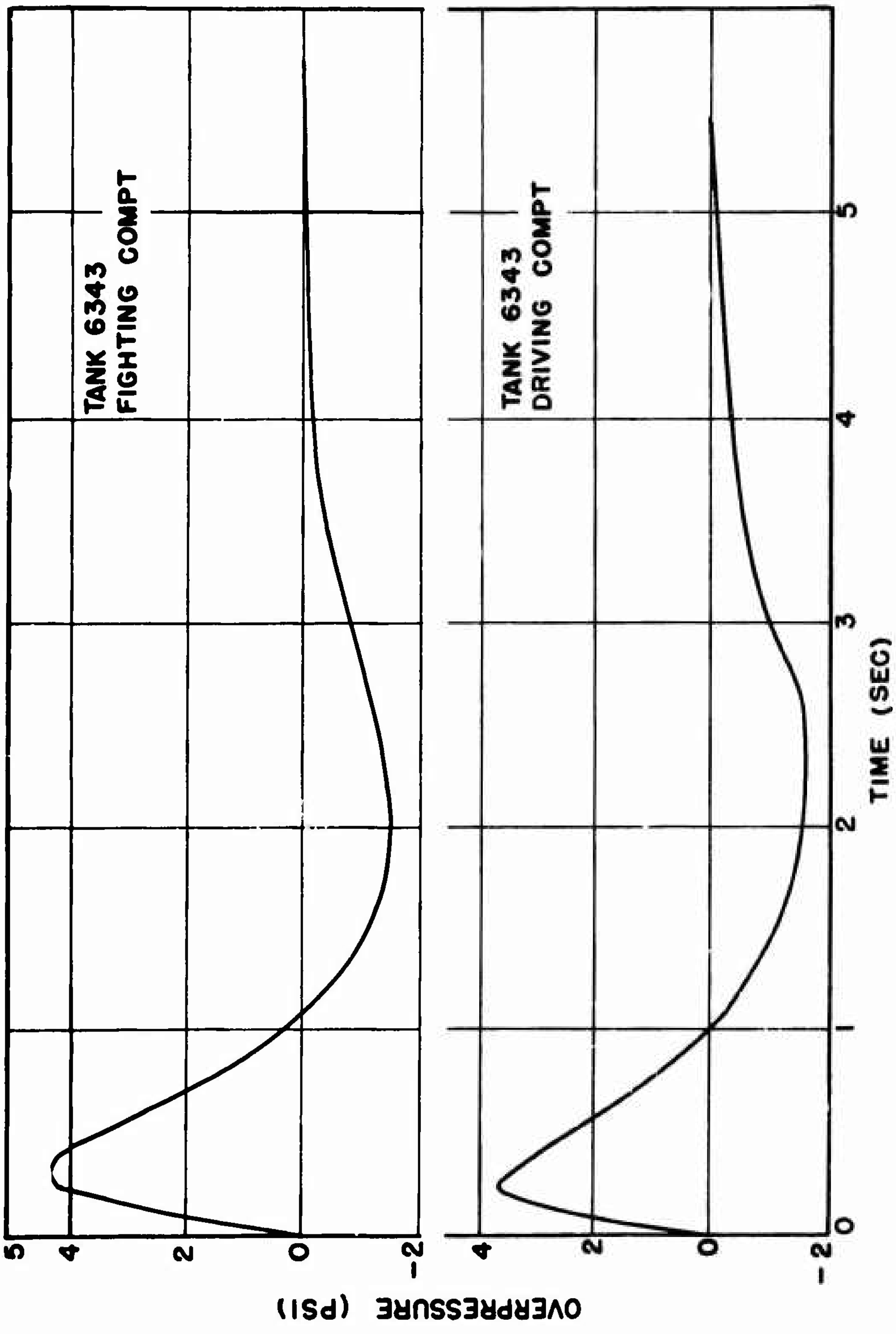

Fig. B.49 Interior Overpressure as a Function of Time for Tail-on Tank at 1233 Yd from Ground Zero (Magnetic Recorder)

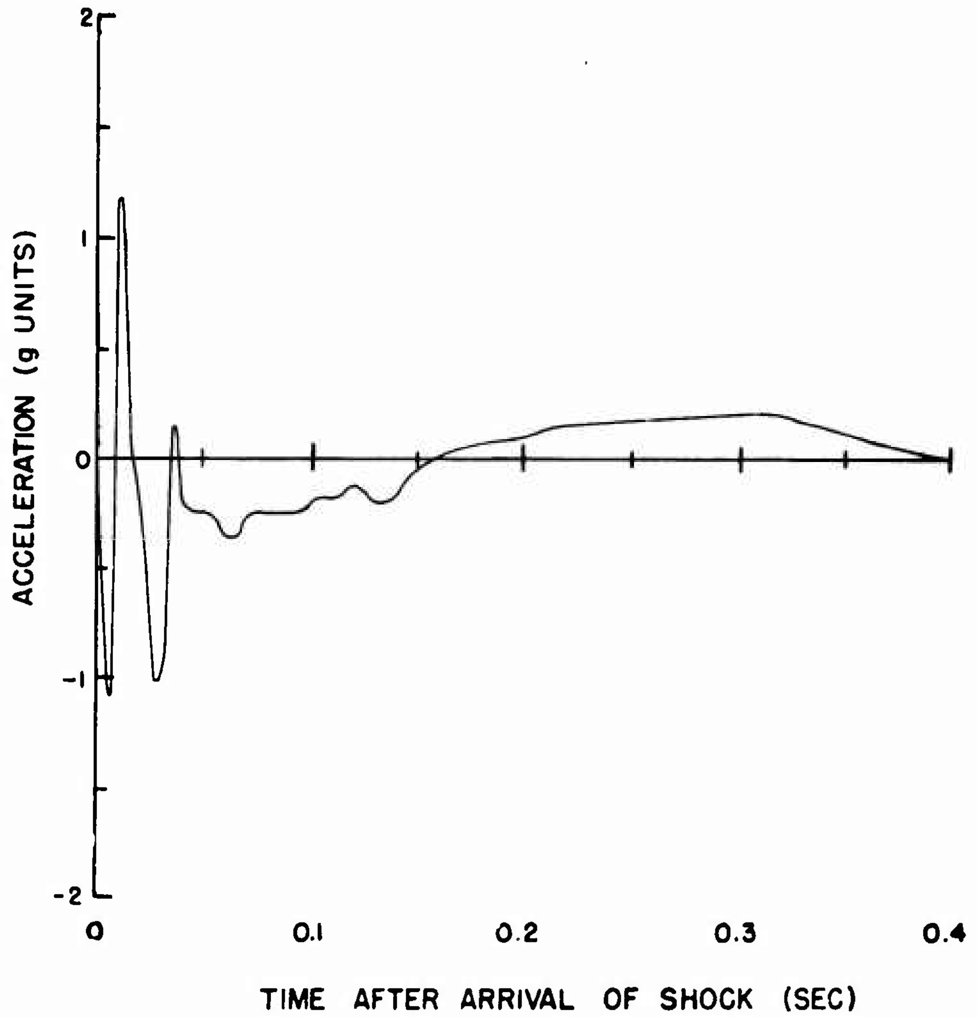

Fig. B.50 Radial Acceleration for Tail-on Tank at 1233 Yd from Ground Zero (Accelerometer 1)

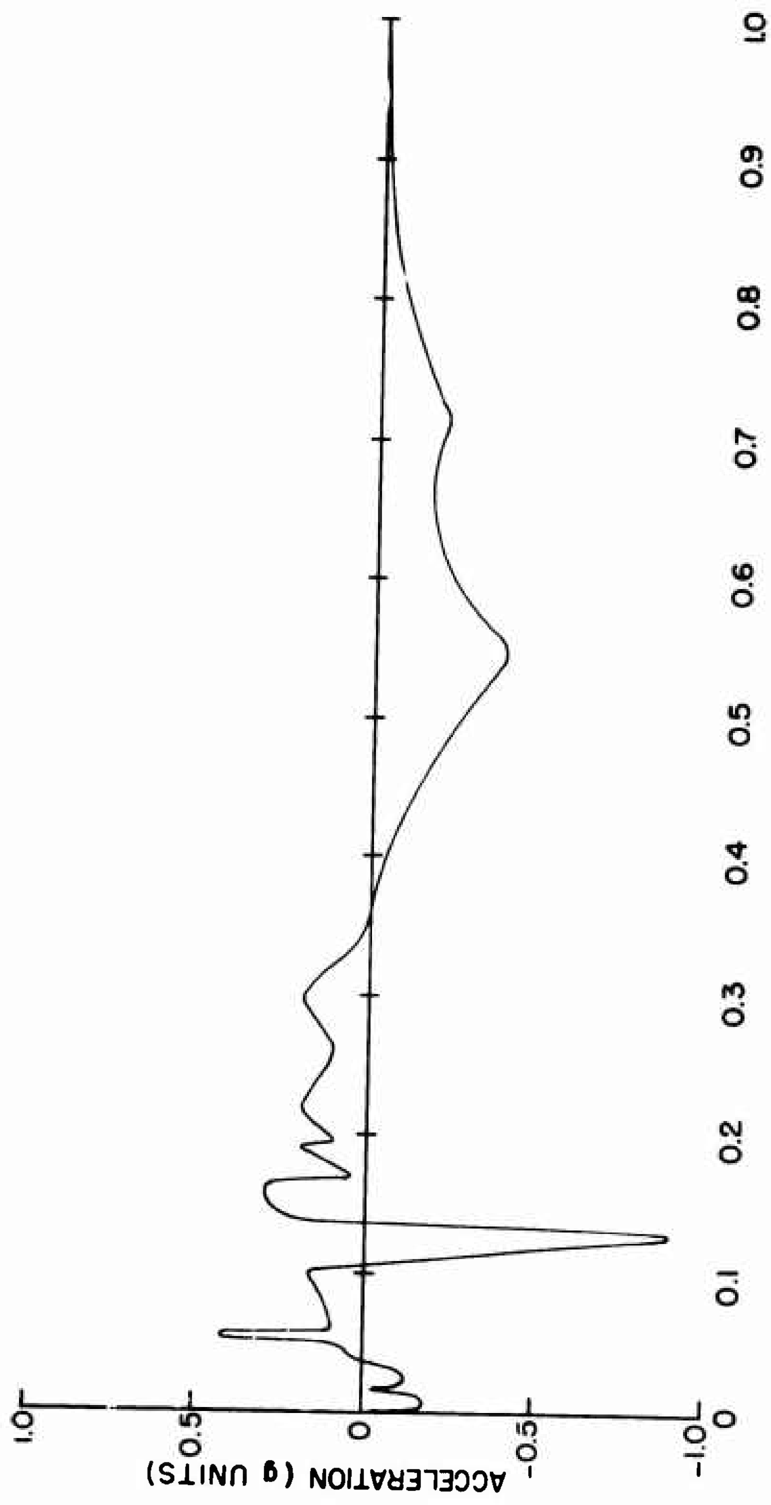

Fig. B.51 Vertical Acceleration for Tail-on Tank at 1233 Yd from Ground Zero (Accelerometer 2)

Appendix C

Details of Automotive Examination

This appendix is in two parts. Part I contains the detailed evaluation of the loss of combat effectiveness of the 10 medium tanks used in the test. Part II contains the detailed evaluation of the damage to the vehicles and the repair time required, from the point of view of the technical service involved, by the Ordnance Corps.

First Lt Robbins L. Wildman, who is responsible for the evaluation in Part I, is an Armored officer, with $2\frac{1}{2}$ years of combat experience. In preparation for his role in Operation Greenhouse, he worked with other Armored officers in the evaluation of damage to tanks in connection with a tank vulnerability program being carried on in BRL.

Such an evaluation, wherein attempts are made to describe loss of combat efficiency in terms of percentage, is obviously highly subjective. The selection of an officer to make such an evaluation must therefore be done with care. It is believed that Lt Wildman's evaluation is a valid example of the reaction of a company-grade officer of the Armored Corps.

For each tank, the results of the examination and the evaluation based on the examination are presented.

Part I—Evaluation of Loss of Combat Effectiveness

C.1 M-46 MEDIUM TANK, NO. 883, RANGE 500 YD, ORIENTED LEFT SIDE TO TOWER

C.1.1 Combat Effectiveness

Estimated immediate combat effectiveness, 0 per cent. This vehicle without its turret is worthless in terms of immediate combat effectiveness.

C.1.2 Fire-control Instruments

Telescope M71C: Lens amber-colored; serviceable

Periscopes M6: Both heads of tank commander's periscope missing; both heads of loader's periscope missing; bottom head of assistant driver's periscope broken; driver's periscope blown out of mount; serviceable

Periscope M10: Lens amber-colored; serviceable

Vane sight: Bent to left

Azimuth indicator: Gears torn loose from turret

Elevation quadrant M9: Bubble glass broken

Other: Numbers 1, 2, and 3 vision blocks cracked and broken

C.1.3 Hatches

Tank commander: Serviceable

Loader: Serviceable

Driver: Serviceable

Assistant driver: Serviceable

Escape: Both blown out; one serviceable, operating handle of the other bent

C.1.4 Fire Power

90-mm

Gun: Serviceable

Elevating mechanism: Bolts holding top of elevating mechanism broken loose from top of turret; electric motor and hydraulic lines torn loose; turret collector ring wires torn loose
Traversing mechanism: Turret torn from mount; unserviceable
Caliber .50 antiaircraft
Gun: Missing
Mount: Pintle broken off in pedestal mount; mount serviceable
Caliber .30 bow
Gun: New barrel and slotted jacket needed
Mount: Serviceable
Caliber .30 coaxial
Gun: Dirty but serviceable
Mount: Serviceable

C.1.5 Communication

Receiver: Jolted loose from mounting base; dirty in appearance; no external damage apparent
Transmitter: Unable to check; appearance satisfactory
Aerial and base: Aerial and insulator missing; flexible base missing
Interphone 606: Boxes serviceable
External interphone: Serviceable

C.1.6 Mobility

Engine performance: Started by using jumper cable from another vehicle; engine not firing on all cylinders; left muffler missing; right muffler and exhaust separated
Transmission performance: Sluggish; low oil pressure; leak in oil coolers
Tracks and suspension: Serviceable
Turning, right: Erratic; bent control and linkage rods
Turning, left: Erratic; bent control and linkage rods
Braking ability: Subnormal
Auxiliary engine: Serviceable

C.2 M-26 MEDIUM TANK, NO. 063, RANGE 500 YD, ORIENTED HEAD TO TOWER

C.2.1 Combat Effectiveness

Estimated immediate combat effectiveness, 75 per cent. This vehicle can be considered at most only 75 per cent effective without radio communication and without a caliber .50 machine gun.

C.2.2 Fire-control Instruments

Telescope M71C: Lens amber-colored; serviceable
Periscopes M6: Both heads of driver's and assistant driver's periscope broken; assistant driver's periscope holder damaged; both heads of tank commander's periscope missing; assistant driver's periscope holder blown in through mount
Periscope M10. Lens amber-colored; serviceable
Vane sight: Bent
Azimuth indicator: Serviceable
Elevation quadrant M9: Serviceable
Other: All vision blocks and cupola, amber

C.2.3 Hatches

Tank commander: Serviceable
Loader: Serviceable
Driver: Serviceable
Assistant driver: Serviceable
Escape: Serviceable

C.2.4 Fire Power

90-mm
Gun: Breech closes slowly; combination of dirt and weak closing spring; elevation traveling lock (inside); unserviceable
Elevating mechanism: Serviceable
Traversing mechanism: Serviceable
Caliber .50 antiaircraft
Gun: Weapon and AA-cradle missing
Mount: Bottom part of pintle (AA-cradle) broken off in pedestal mount; pedestal mount serviceable
Caliber .30 bow
Gun: Serviceable
Mount: Serviceable
Caliber .30 coaxial
Gun: Serviceable
Mount: Serviceable

C.2.5 Communication

Receiver: Appears serviceable; unable to make complete check without aerial base
Transmitter: Appears serviceable; unable to make complete check without aerial base
Aerial and base: Aerial and aerial base missing

Interphone 606: Appearance satisfactory; see receiver and transmitter above
External interphone: External interphone box still intact and mounted on hull

C.2.6 Mobility

Engine performance: Serviceable
Transmission performance: Serviceable
Tracks and suspension: Serviceable; appearance good
Turning, right: Serviceable
Turning, left: Serviceable
Braking ability: Serviceable
Auxiliary engine: No damage

C.3 M-26 MEDIUM TANK, NO. 120, RANGE 750 YD, ORIENTED REAR TO TOWER

C.3.1 Combat Effectiveness

Estimated immediate combat effectiveness, 0 per cent. This vehicle after being righted could not be operated because of a punctured engine oil pan. The major weapon could not be used because of a broken elevating mechanism. These two conditions are sufficient to reduce this vehicle to 0 per cent combat effectiveness.

C.3.2 Fire-control Instruments

Telescope M71C: Corroded by acid*
Periscopes M6: Both heads of loader's periscope missing; top head of tank commander's periscope missing; bottom head of driver's periscope missing
Periscope M10: Corroded by acid
Vane sight: Serviceable
Azimuth indicator: Corroded by acid
Elevation quadrant M9: Serviceable
Other: Number 1 vision block cracked

C.3.3 Hatches

Tank commander: Serviceable
Loader: Serviceable
Driver: Serviceable
Assistant driver: Serviceable
Escape: Driver's escape hatch blown out; serviceable

*Whenever the notation "corroded by acid" appears in this Appendix, it refers to corrosion induced by spillage of electrolyte from the batteries used for instrumentation

C.3.4 Fire Power

90-mm
Gun: Serviceable
Elevating mechanism: Elevating mechanism unserviceable; gun can be moved up and down freely by lifting by hand; impossible to turn elevating handle, bent
Traversing mechanism: Turret lock frozen, able to traverse after freeing turret lock

Caliber .50 antiaircraft
Gun: Missing, also AA-cradle
Mount: Pedestal; serviceable

Caliber .30 bow
Gun: Unserviceable; impossible to pull bolt to rear; slotted jacket bent; gun barrel bent
Mount: Serviceable

Caliber .30 coaxial
Gun: Unserviceable because of acid corrosion
Mount: Unserviceable because of acid corrosion

C.3.5 Communication

Receiver: Unable to check because of spilled acid; external appearance satisfactory
Transmitter: Unable to check because of spilled acid; external appearance satisfactory
Aerial and base: Insulator gone; one and one-half sections of aerial missing; remainder of aerial loose in mounting hole with flexible base attached
Interphone 606: No apparent damage to boxes; headsets covered with acid
External interphone: Closing handle bent on top end; remainder of box and phone serviceable

C.3.6 Mobility

Engine performance: Unserviceable; see damage report
Transmission performance: No visible damage
Tracks and suspension: Serviceable; functioned satisfactorily when towed
Turning, right: Unable to check without power
Turning, left: Unable to check without power
Braking ability: Unable to check without power
Auxiliary engine: Serviceable

C.4 M-26 MEDIUM TANK, NO. 954, RANGE 750 YD, ORIENTED LEFT SIDE TO TOWER

C.4.1 Combat Effectiveness

Estimated immediate vehicle combat effectiveness, 0 per cent. This vehicle after being righted could not be operated with one track fouled by a bent road-wheel arm and wheel. The major weapon could not be operated because of a frozen turret lock which prevented traversing. These two conditions, in addition to its being overturned, are sufficient to reduce the vehicle to 0 per cent combat effectiveness.

C.4.2 Fire-control Instruments

Telescope M71C: Corroded by acid
Periscopes M6: Bottom head of driver's periscope missing; top head of driver's auxiliary periscope broken
Periscope M10: Corroded by acid
Vane sight: Bent
Azimuth indicator: Corroded by acid
Elevation quadrant M9: Serviceable
Other: Numbers 1 and 2 vision blocks etched by acid; Nos. 1, 3, and 5 vision blocks broken

C.4.3 Hatches

Tank commander: Serviceable
Loader: Hard to open; will not close completely
Driver: Serviceable
Assistant driver: Serviceable; opens and closes stiffly
Escape: Serviceable

C.4.4 Fire Power

90-mm
- Gun: Could not open breech because of acid corrosion
- Elevating mechanism: Serviceable
- Traversing mechanism: Handle covered with acid; traversing mechanism serviceable after removing damaged turret lock

Caliber .50 antiaircraft
- Gun: Receiver full of dirt; unable to work bolt
- Mount: Pedestal loose on turret

Caliber .30 bow
- Gun: Slotted jacket bent; removed with torch
- Mount: Serviceable

Caliber .30 coaxial
- Gun: Serviceable
- Mount: Serviceable

C.4.5 Communication

Receiver: Unable to make full check because of missing aerial base; appears serviceable
Transmitter: Unable to make full check because of missing aerial base; appears serviceable
Aerial and base: Aerial and base missing
Interphone 606: Headsets and microphones covered with acid
External interphone: External interphone box torn from hull

C.4.6 Mobility

Engine performance: Serviceable; started with jumper cable from another vehicle
Transmission performance: Serviceable
Tracks and suspension: Two holes in No. 5 road wheel, right side; No. 4 road-wheel arm bent, right side; arm and road wheel removed; track operation and suspension still satisfactory with road wheel missing
Turning, left: Serviceable
Braking ability: Serviceable

C.5 M-26 MEDIUM TANK, NO. 257, RANGE 750 YD, ORIENTED HEAD TO TOWER

C.5.1 Combat Effectiveness

Estimated immediate vehicle combat effectiveness, 75 per cent. This vehicle without caliber .50 machine gun is still 75 per cent immediately combat effective.

C.5.2 Fire-control Instruments

Telescope M71C: Serviceable
Periscopes M6: Both heads of driver's periscope missing; both heads of assistant driver's periscope missing
Periscope M10: Serviceable
Vane sight: Serviceable
Azimuth indicator: Serviceable
Elevation quadrant M9: Serviceable
Other: Numbers 4 and 5 vision blocks chipped and cracked

C.5.3 Hatches

Tank commander: Serviceable
Loader: Serviceable
Driver: Serviceable
Assistant driver: Serviceable
Escape: Serviceable

C.5.4 Fire Power

90-mm
- Gun: Serviceable
- Elevating mechanism: Serviceable
- Traversing mechanism: Slow manual traverse; no power traverse

Caliber .50 antiaircraft
- Gun: Gun and cradle missing
- Mount: Serviceable

Caliber .30 bow
- Gun: Serviceable
- Mount: Serviceable

Caliber .30 coaxial
- Gun: Serviceable
- Mount: Serviceable

C.5.5 Communication

Receiver: Serviceable
Transmitter: Serviceable
Aerial and base: Two top sections of aerial missing
Interphone 606: Serviceable
External interphone: Serviceable

C.5.6 Mobility

Engine performance: Serviceable
Transmission performance: Serviceable
Tracks and suspension: Flapping fenders hit track, do not affect mobility
Turning, right: Serviceable
Turning, left: Serviceable
Braking ability: Serviceable
Auxiliary engine: Serviceable

C.6 M-26 MEDIUM TANK, NO. 117. RANGE 1000 YD, ORIENTED LEFT SIDE TO TOWER

C.6.1 Combat Effectiveness

Estimated immediate vehicle combat effectiveness, barely 75 per cent. This vehicle without a caliber .30 bow machine gun and with a broken aerial base may be considered barely 75 per cent combat effective.

C.6.2 Fire-control Instruments

Telescope M71C: Serviceable
Periscopes M6: Serviceable
Periscope M10: Serviceable
Vane sight: Serviceable
Azimuth indicator: Serviceable
Elevation quadrant M9: Serviceable

C.6.3 Hatches

Tank commander: Serviceable
Loader: Serviceable
Driver: Serviceable
Assistant driver: Serviceable
Escape: Serviceable

C.6.4 Fire Power

90-mm
- Gun: Serviceable
- Elevating mechanism: Serviceable
- Traversing mechanism: Serviceable

Caliber .50 antiaircraft
- Gun: Serviceable after cleaning
- Mount: Serviceable

Caliber .30 bow
- Gun: Slotted jacket bent; not immediately usable; weapon frozen in mount; weapon serviceable after removal from mount
- Mount: Serviceable after cleaning

Caliber .30 coaxial
- Gun: Serviceable
- Mount: Serviceable

C.6.5 Communication

Receiver: Serviceable
Transmitter: Serviceable
Aerial and base: Aerial missing; insulator base serviceable; flexible mounting base missing
Interphone 606: Serviceable
External interphone: Serviceable

C.6.6 Mobility

Engine performance: Serviceable
Transmission performance: Serviceable
Tracks and suspension: Serviceable
Turning, right: Serviceable
Turning, left: Serviceable

Braking ability: Serviceable
Auxiliary engine: Serviceable

C.7 M-26 MEDIUM TANK, NO. 440, RANGE 1000 YD, ORIENTED HEAD TO TOWER

Estimated immediate vehicle combat effectiveness, 100 per cent. This vehicle may be considered completely serviceable for immediate combat use. All elements of fire-control instruments, hatches, fire power, communication, and mobility (fender hits track intermittently, but this does not affect vehicle mobility) were checked and found to be serviceable.

C.8 M-46 MEDIUM TANK, NO. 872, RANGE 1233 YD, ORIENTED LEFT SIDE TO TOWER

Estimated immediate vehicle combat effectiveness, 100 per cent. This vehicle may be considered completely serviceable for immediate combat use. All elements of fire-control instruments, hatches, fire power, communication, and mobility were checked and found to be serviceable.

C.9 M-26 MEDIUM TANK, NO. 424, RANGE 1233 YD, ORIENTED REAR TO TOWER

Estimated immediate vehicle combat effectiveness, 100 per cent. This vehicle may be considered completely serviceable for immediate combat use. All elements of fire-control instruments, hatches, fire power, communication, and mobility we e checked and found to be serviceable.

C.10 M-26 MEDIUM TANK, NO. 418, RANGE 1400 YD, ORIENTED LEFT SIDE TO TOWER

Estimated immediate vehicle combat effectiveness, 100 per cent. This vehicle may be considered completely serviceable for immediate combat use. All elements of fire-control instruments, hatches, fire power, communication, and mobility were checked and found to be serviceable.

Part II—Evaluation of Required Maintenance and Repairs

C.11 DAMAGE TO VEHICLES AND REPAIR TIME REQUIRED

The evaluation in Part II was prepared by Capt David U. Armstrong, Ordnance Department, Automotive Proof Officer from the Automotive Division, Development and Proof Services, Aberdeen Proving Ground. He was assisted by Charles E. Depkin, Automotive Engineer; M/Sgt George W. Eason, Ordnance; and Sgt Thomas E. Murphy, Ordnance. Sergeants Eason and Murphy both have had combat experience with ordnance automotive-maintenance organizations.

Detailed listing of all damage is presented, with estimates of the time and man-hours required for repairing such damage, in Tables C.1 to C.10. In cases of doubt, actual time trials were conducted.

TABLE C.1 M-46 MEDIUM TANK, NO. 883, RANGE 500 YD, ORIENTED LEFT SIDE TO TOWER
(Depot Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Fenders Mudguards Boxes, stowage, hull all missing on left side of vehicle	Replace	4	8		32
Outriggers all bent on left side of vehicle	Replace	2	2		4
Fender, front Fender, rear bent on right side of vehicle	Repair	2	4		.8
Headlights, service, assembly destroyed	Replace	1	1		1
Headlight guard bent on right side of vehicle	Repair	1		30	½
Headlight guard missing on left side of vehicle	Replace	2		30	1
Fender extension, front missing on right side of vehicle	Replace	2	1		2
Box, stowage, hull rear stowage box on right side of vehicle missing	Repair	2	2		4
Linkage, steering interference in system	Repair	1	1		1
Muffler, exhaust, assembly Bracket, mounting, muffler right muffler seams split and mounting brackets pulled loose	Repair	2	3		6

TABLE C.1 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Muffler, exhaust, assembly Pipe, ball joint, exhaust, outer assembly left muffler missing and outer exhaust-pipe section destroyed	Replace	2	1	30	3
Door, engine compartment, grille Hinge, door, engine compartment, grille, right three doors missing and door hinge broken	Replace and repair	2	2		4
Battery, storage, lead-acid, No. 6TN two batteries over left gas tank cracked	Replace	2		30	1
Arm, intermediate and rear road wheel two on left side of vehicle slightly bent	Replace	4	8		32
Shovel, short-handle Handle, mattock Handle, sledge, blacksmith's double-faced, 10 lb shovel and mattock handle missing and sledge handle broken	Replace				
Roller, track support, rear rear roller on left side of vehicle bent	Replace	2	1		2
Bolt, locking lever, gun-traveling lock sheared	Replace	1		30	½
Retainer, track, spare shoe, turret, exterior Retainer, fixture, track connecting, turret, exterior both retainers bent	Repair	2	1		2

TABLE C.1 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Door, driver's escape hatch, assembly Lever, release, escape hatch door two doors blown out; lever broken on one door and bent on other	Replace	2	2		4
Gun, machine, caliber .30, flexible bow barrel and jacket bent	Replace	1	1		1
Door, driver's, assembly Door, assistant driver's, assembly Door, gun loader's escape hatch, assembly all blown open; no damage					
Periscope, M6 Periscope, M10 all M6 periscopes broken or blown into vehicle; M10 periscope undamaged	Replace	1		30	½
Block, direct-vision two broken	Replace	1	1		1
Gun, machine, caliber .50 Mount, caliber .50 machine gun, AA both missing	Replace	2		30	1
Body, turret, tank, M-46 blown clear of tank; all turret-to-hull electrical connections broken	Complete rebuild of turret	4	16		64
Bolts, bracket, elevating mechanism sheared off	Replace	1	1		1
Periscope, M6, driver's blown out but serviceable	Replace				

TABLE C.1 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Head, periscope, M6, assistant driver's broken	Replace				
Cradle, mounting, air cleaner broken	Replace	2		30	1
Indicator, azimuth, M20 gear teeth stripped	Replace	1	2		2
Engine, continental, Model AV-1790-5A, assembly engine not firing properly	Repair	1	1		1
Radiator, transmission, cooler, assembly leaks	Repair	2	6		12
Total			69		192.5

TABLE C.2 M-26 MEDIUM TANK, NO. 063, RANGE 500 YD, ORIENTED HEAD TO TOWER
(Organizational Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Fenders, front left, crumpled; right, missing	Replace	4	2		8
Fenders, rear both missing	Replace	4	2		8
Cover, box, stowage, hull left front crumpled	Repair	2	1		2
Mudguard left front bent	Repair	2	1		2
Mudguards Boxes, stowage, hull left rear and intermediate boxes and guards missing	Replace	4	4		16
Cover, box stowage, hull Box, stowage, hull right front box lifted from outriggers and cover missing	Replace and repair	2	3		6
Periscope, M6, assistant driver's Head, periscope, M6, assistant driver's periscope blown through mount and top head broken	Replace	1		30	½
Headlights, service, assembly Headlight guards both severely damaged	Replace	2	1		2
Head, periscope, M6, driver's top and bottom heads broken	Replace	1		30	½

TABLE C.2 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Head, periscope, M6 both heads of tank commander's periscope missing; top head of loader's periscope missing	Replace	1		30	½
Gun, machine, caliber .50 Mount, caliber .50 machine gun, AA both missing; mount broken off at the pintle	Replace	2		30	1
Antenna, mast base, mast sections, MS-116, MS-117, MS-118 blown off	Replace	2		30	1
Clip, arm, traveling missing	Replace	1		30	½
Arm, traveling clip, turret, caliber .50 machine gun bent	Repair	1		30	½
Box, stowage, periscope and spare parts, radio displaced into fighting compartment	Repair	1		30	½
Lock, travel, elevation bent	Replace	1	1	30	1½
Total			20		52.5

TABLE C.3 M-26 MEDIUM TANK, NO. 120, RANGE 750 YD, ORIENTED REAR TO TOWER*
(Field Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time		Total Man-hours
			Hr	Min	
Fenders front and rear fenders, left side, badly bent	Replace	2	4		8
Shield, dust all dust shields on left side of vehicle badly bent	Replace	2		30	1
Mudguards all mudguards on left side of vehicle bent	Replace	2	2		4
Box, stowage, hull rear stowage box on left side of vehicle collapsed	Replace	2	2		4
Gusset, hull, outrigger Outrigger outrigger and gusset for rear stowage box on left side of vehicle torn from hull	Repair	1		30	½
Fenders, right side Shield, dust, right side Mudguards, right side all bent as on left side of vehicle	Replace	1	6	30	6½
Box, stowage, hull the rear and intermediate stowage boxes on the right side of vehicle collapsed	Replace	2	2		4
Gusset, hull, outrigger, right side Outrigger, right side outrigger and gusset for rear stowage box on right side of vehicle torn from hull	Repair	1		30	½

TABLE C.3 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Headlights, service assembly both destroyed	Replace	2		30	1
Arm, traveling clip, turret, caliber .50 machine gun bent	Repair	1		30	½
Antenna, mast base, mast, MS-116, MS-117, MS-118 destroyed	Replace	2		30	1
Gun, machine, caliber .50 Mount, caliber .50 machine gun, AA missing	Replace	1		30	½
Head, periscope, M6, top head tank commander's periscope destroyed	Replace				
Guard, periscope, M6, loader's bent	Repair	1		30	½
Retainer, fixture, track connecting, turret, exterior torn and bent	Repair	1		30	½
Mechanism, turret, traversing, hand stiff					
Retainer, track, spare shoe torn and bent	Repair	2	3		6
Shoe, spare, track missing	Replace				
Cover, 90-mm gun shield, assembly destroyed	Replace				
Grille, air exhaust, engine compartment, assembly front right and rear right grille assemblies torn loose	Repair				

TABLE C.3 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Box, telephone cover hinge and latch bent	Repair	1	1		1
Taillight, left, assembly Taillight, right, assembly both destroyed	Replace	1	1	30	1½
Sight, vane, turret, assembly bent	Repair				
Periscope, M10 destroyed	Replace				
Telescope, M71C objective lens chipped	Replace				
Lock, turret, traversing, assembly jammed	Replace	1	1		1
Mechanism, elevating, assembly broken	Replace	2	4		8
Gun, machine, caliber .30, bow barrel, barrel jacket, and receiver bent	Replace	1		30	½
Mounting, engine, assembly right engine mounting broken	Replace				
Pan, oil, engine left side of oil pan punctured by broken engine mounting	Replace	4	12		36
Total			74		93

*The vehicle engine is mounted in vehicle backwards with regard to the position of the vehicle.

TABLE C.4 M-26 MEDIUM TANK, NO. 257, RANGE 750 YD, ORIENTED HEAD TO TOWER
(Field Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Fender right and left front fenders badly damaged	Replace	4	4		16
Headlights, service, assembly badly damaged	Replace	1	1		1
Brace, fender right front fender brace bent	Repair	2		30	1
Brace, fender left front fender brace missing	Replace	1		30	½
Shield, dust front dust shield missing on right side of vehicle	Replace	2	1		2
Mudguards rear and center mudguards bent on right side of vehicle	Repair	2	2		4
Shield, dust rear dust shield missing on right side of vehicle	Replace	2	1		2
Shield, dust one center dust shield missing on right side of vehicle	Replace	2	1		2
Box, stowage, hull all stowage boxes on right side of vehicle badly damaged	Replace	2	4		8
Fender right rear fender buckled up	Replace	2	2		4
Fender left rear fender buckled slightly	Repair	2	1		2

TABLE C.4 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Mudguards all mudguards bent on left side of vehicle	Repair	2	3		6
Shield, dust front and center dust shield missing on right side of vehicle	Replace	2	2		4
Cover, box, stowage, hull intermediate stowage box cover on left side of vehicle was badly damaged	Replace or repair	2	2		4
Retainer, track, spare shoe, turret, exterior missing	Replace	2	1		2
Retainer, fixture, track connecting, turret, exterior missing	Replace				
Head, periscope, M6 both heads of driver's and assistant driver's periscopes missing	Replace	1		30	½
Antenna, mast sections, MS-117, MS-118 broken off	Replace	1		30	½
Block, direct-vision two chipped	Replace	1	1		1
Cover, 90-mm gun shield badly damaged	Replace	2	2		4
Gun, machine, caliber .50 Mount, machine gun caliber .50, AA missing	Replace	2		30	1
Arm, traveling clip, turret, caliber .50 machine gun bent	Repair	1		30	½

TABLE C.4 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Door, periscope housing, assembly Guard, periscope housing, assembly loader's periscope guard and door damaged	Repair	2		30	1
Door, periscope housing, assembly Guard, periscope housing, assembly driver's and assistant driver's periscope guard and door damaged	Repair	2		30	1
Grip, engine compartment grille missing	Replace	1		30	½
Mechanism, turret, traversing, power does not operate	Repair	2	2		4
Mechanism, turret, traversing, hand operates slow and stiff	Repair	2	1		2
Total			34	30	74.5

TABLE C.5 M-26 MEDIUM TANK, NO. 954, RANGE 750 YD, ORIENTED LEFT SIDE TO TOWER
(Field Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Fenders Mudguards Box, stowage, hull front and rear fenders missing, all stowage boxes missing, and all mudguards missing on left side of vehicle	Replace	4	8		32
Outrigger outrigger for rear stowage box on left side of vehicle bent	Repair	2		30	1
Fenders front and rear fenders bent on right side of vehicle	Repair	4	2		8
Shields, dust all crumpled on right side of vehicle	Replace	2	2		4
Mudguards all crumpled on right side of vehicle	Replace	2	2		4
Outrigger outrigger for rear stowage box on right side of vehicle bent	Repair	2	1		2
Arm, rear and intermediate road wheel Disk, wheel assembly No. 4 intermediate road-wheel arm and disk bent	Replace	4	8		32
Headlights, service both destroyed	Replace	1	1		1

TABLE C.5 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Headlight guards guard for left headlight destroyed	Replace	2		30	1
Head, periscope, M6 both heads of driver's periscope broken and top head of driver's auxiliary periscope broken	Replace	1		30	½
Arm, traveling clip, turret, caliber .50 machine gun broken	Replace	1		30	½
Antenna, mast base, mast sections, MS-116, MS-117, MS-118 missing	Replace	2		30	1
Gun, machine, caliber .30, bow barrel and barrel jacket bent	Replace	1		30	½
Gun, machine, caliber .50 Mount, caliber .50 machine gun, AA damaged	Repair	1		30	½
Retainer, hood hatch, driver's right and left destroyed	Replace	2	2		4
Retainer, fixture, track connecting, turret, exterior missing	Replace	1		30	½
Periscope, M10 destroyed	Replace	1		30	½
Door, engine compartment, grille, air exhaust front left door torn off	Replace hinge pin	2	1		2
Hinge, door, engine compartment, grille, air exhaust right rear door hinge sprung	Repair	2	2		4

TABLE C.5 (Continued)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Box, telephone torn off	Repair	2		30	1
Taillight, left, assembly Taillight, right, assembly both destroyed	Replace	2	1		2
Taillight guards both damaged	Repair	1	1		1
Lock, turret, traversing, assembly jammed	Replace	1	1		1
Hatch, turret, gun loader's, assembly sprung	Repair	1	1		1
Total			36		105

TABLE C.6 M-26 MEDIUM TANK, NO. 117, RANGE 1000 YD, ORIENTED LEFT SIDE TO TOWER
(Field Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Fender left-front and left-rear fenders missing	Replace	2	3		6
Box, stowage, hull left rear and intermediate boxes missing	Replace	2	2		4
Box, stowage, hull left front box badly damaged	Replace	2	2		4
Mudguard all mudguards on the left side of the vehicle missing	Replace	2	2		4
Headlight, service, assembly Headlight guard destroyed	Replace	2	1		2
Brace, fender left-front and left-rear fender braces missing	Replace	2		30	1
Paint, left side of vehicle scorched and sandblasted	Repaint	1	1		1
Retainer, hood, driver's and assistant driver's hatch bent	Repair	2	1		2
Cover, 90-mm gun shield, assembly destroyed	Replace	2	2		4
Antenna, mast base, mast sections mast base broken and mast sections missing	Replace	2	1		2
Fender right-front and right-rear fenders bent	Repair	2	1		2
Gun, machine, caliber .50 scorched	Clean	1		30	
Total			17		32.5

TABLE C.7 M-26 MEDIUM TANK, NO. 440, RANGE 1000 YD, ORIENTED HEAD TO TOWER
(Organizational Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Paint, front of vehicle scorched and sandblasted	Repaint	1	2		2
Headlights, service, assembly destroyed	Replace	1	1		1
Fender right-front and left-front fenders buckled	Repair	4	2		8
Antenna, mast sections bent but still serviceable					
Mudguard right-front mudguard bent	Repair	1		30	½
Mudguard left-front mudguard bent	Repair	1		30	½
Brace, fender right-front fender brace missing	Replace	1	1		1
Brace, fender left-front fender brace broken and bent	Repair	1		30	½
Total			7	30	13.5

TABLE C.8 M-46 MEDIUM TANK, NO. 872, RANGE 1233 YD, ORIENTED LEFT SIDE TO TOWER
(Organizational Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Fender left-front and left-rear fenders buckled	Repair	2	1		2
Brace, fender left-front and left-rear fender braces bent	Repair	2		30	1
Antenna, mast sections bent slightly					
Muffler, exhaust, assembly Bracket, mounting, muffler muffler punctured and muffler mounting bracket torn loose	Repair	2	3		6
Clamp, exhaust-pipe-to-engine outlet assembly broken	Replace	1		30	½
Fender left-rear fender separated from mudguard	Repair	1		30	½
Cover, 90-mm gun shield, assembly badly scorched	Replace	2	2		4
Vehicle, left side, toward tower; right side left side scorched right side unmarked					
Absorber, shock left-front shock absorber dented					
Total			7	30	14

TABLE C.9 M-26 MEDIUM TANK, NO. 424, RANGE 1233 YD, ORIENTED REAR TO TOWER
(Organizational Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Paint, rear of vehicle scorched and sandblasted	Repaint	2	2		4
Antenna, mast sections, MS-117, MS-118 top two sections broken off	Replace	1		30	½
Total			2	30	4½

TABLE C.10 M-26 MEDIUM TANK, NO. 418, RANGE 1400 YD, ORIENTED LEFT SIDE TO TOWER
(Organizational Maintenance)

Description of Damage	Necessary Action Required	Number of Maintenance Personnel Required	Maintenance Time Hr	Maintenance Time Min	Total Man-hours
Fender left-front and left-rear fender buckled	Straighten	2	1		2
Brace, fender left-front and left-rear fender brace bent	Straighten	2	1		2
Cover, 90-mm gun shield, assembly burned	Replace	2	2		4
Paint, left side of vehicle scorched	Repaint	1	1		1
Total			5		9

Appendix D

Roster of Personnel

Armstrong, David U., Capt: Supply Division, Headquarters Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio. Supervision of all automotive work, preparation and servicing of vehicles and evaluation of damage. Supervised preparation of Appendix C and prepared Part II of Appendix C.

Arnold, Norman W.: Ballistic Research Laboratories (ORDBG-BRL-M) Aberdeen Proving Ground, Md. Project Officer. Prepared Chaps. 4, 6, and 7 of final report.

Berning, Warren W.: Ballistic Research Laboratories (ORDBG-BRL-M) Aberdeen Proving Ground, Md. Accomplished or supervised preoperation theoretical work. Prepared Chaps. 1, 2, 3, and 5 of final report. Supervised preparation of Appendix B.

Colburn, Victor R.: Ballistic Research Laboratories (ORDBG-BRL-M) Aberdeen Proving Ground, Md. Supervised preparation and calibration of instrumentation. Prepared Appendix A of final report.

Conley, Joseph M.: Department of Physics, Ohio State University, Columbus, Ohio. Prepared and calibrated Sanborn recorders.

Depkin, Charles E.: Automotive Division, D&PS, Aberdeen Proving Ground, Md. Evaluated damage to vehicles and maintenance time required for repairs.

Drewry, Guy H., Jr., Maj: Office Chief of Ordnance (ORDTB) Washington 25, D. C. Served as administrative officer.

Eason, George W., M/Sgt: Automotive Division, D&PS, Aberdeen Proving Ground, Md. Prepared and maintained vehicles. Assisted in evaluation of damage.

Holtzworth, Richard E.: Melpar, Inc., Alexandria, Va. Prepared and calibrated temperature gauges. Installed instrumentation in vehicles.

Marshall, H. Charles, Jr.: Ballistic Research Laboratories (ORDBG-BRL-M), Aberdeen Proving Ground, Md. Designed instrument installation and placement. Prepared and calibrated ERA accelerometers. Prepared accelerometer records.

Murphy, Thomas H., Sgt: Automotive Division, D&PS, Aberdeen Proving Ground, Md. Prepared and maintained vehicles. Assisted in evaluation of damage.

Squires, Reginald K.: Naval Ordnance Laboratory, White Oak, Md. Assisted in preparation and calibration of Webster-Chicago equipment and associated sensing devices, and in preparation of final records from that equipment.

Wildman, Robbins L., 1st Lt: Headquarters, U. S. Army, Ft. Richardson, Alaska. Evaluated impairment of combat effectiveness. Prepared Part I of Appendix C of final report.

Wood, Edward E.: Sandia Corporation, Albuquerque, N. Mex. Prepared and calibrated Webster-Chicago equipment and associated sensing devices. Prepared final records from Webster-Chicago recorders.

Appendix E

Shipping Schedule

	Weight	Cubage (cu ft)
Forward-Sea	483 tons	24,088
Air	839 lb	29
Return-Sea	485 tons	25,132
Air	1348 lb	88

AEC, Oak Ridge, Tenn., A31975